INTEGRATED RENEWABLE RESOURCE MANAGEMENT FOR U.S. INSULAR AREAS

Volume II--Commissioned Papers

Part C: Agriculture - Caribbean

1. Assessment of Semiarid Agricultural Production Technologies for the U.S.-Affiliated Caribbean Islands
   (Gregory L. Morris and Douglas J. Pool)

2. Assessment of Agricultural Production Technologies for U.S. Caribbean Islands
   (Jose Vicente-Chandler)

3. Assessment of Agricultural Crop Production Technologies in Puerto Rico
   (Fernando Castillo-Barahona and Mohinder S. Bhatia)

4. Assessment of Agricultural Crop Production Technologies in the U.S. Virgin Islands
   (Eric Dillingham)

5. Assessment of Livestock Production Technologies in U.S.-Affiliated Caribbean Islands
   (Ruben Caro-Costas)

6. The Puerto Rico Food Processing Industry: Assessment of Food Processing Technologies
   (Ferdinand Sanchez-Nieva)

7. Assessment of Energy-Intensive Farming Technologies for U.S. Insular Areas
   (Alex G. Alexander)

December 1986

These Commissioned Papers were prepared by the outside contractors as an input to an ongoing Office of Technology Assessment (OTA). They do not necessarily reflect the analytical findings of OTA, the Advisory Panel, or the Technology Assessment Board

J952-34

Table of Contents

Part C: Agriculture - Caribbean

1. Assessment of Semiarid Agricultural Production Technologies for the U.S.-Affiliated Caribbean Islands (Gregory L. Morris and Douglas J. Pool) 2
2. Assessment of Agricultural Production Technologies for U.S. Caribbean Islands (Jose Vicente-Chandler) 63
3. Assessment of Agricultural Crop Production Technologies in Puerto Rico (Fernando Castillo-Barahona and Mohinder S. Bhatia) 163
4. Assessment of Agricultural Crop Production Technologies in the U.S. Virgin Islands (Eric Dillingham) 183
5. Assessment of Livestock Production Technologies in U.S.-Affiliated Caribbean Islands (Ruben Caro-Costas) 215
6. The Puerto Rico Food Processing Industry: Assessment of Food Processing Technologies (Ferdinand Sanchez-Nieva) 268
7. Assessment of Energy-Intensive Farming Technologies for U.S. Insular Areas (Alex G. Alexander) 321

Background Paper No. 1

ASSESSMENT OF SEMIARID AGRICULTURAL PRODUCTION TECHNOLOGIES FOR THE U.S.-AFFILIATED CARIBBEAN ISLANDS

by

Gregory L. Morris
and
Douglas J. Pool

1986

Prepared for

U.S. Congress, Office of Technology Assessment,
Integrated Renewable Resource Management for U.S. Insular Areas,
Washington D.C.: U.S. Government Printing Office, 1987.

2

Assessment of Semiarid Agricultural Production Technologies for the U.S. Affiliated Caribbean Islands

Gregory L. Morris and Douglas J. Pool

ABSTRACT

The semi-arid agricultural zone of the U.S. Caribbean consists of Puerto Rico's southern coast and the Island of St. Croix. Sugarcane, the principal crop for over a century, can no longer be produced profitably. No new profitable crops have yet been developed on a substantial commercial scale to replace sugarcane, and the agricultural sector has shrunk dramatically.

Local farmers, who pay federal minimum wage, compete against low wage areas elsewhere in the Caribbean basin and highly efficient producers on the mainland. U.S. Caribbean farmers must adopt efficient high-yield production systems to survive economically. However, local farmers, extensionists and researchers all lack adequate experience with this technology. Commercially viable production techniques have not yet been developed and proven for many potentially profitable crops. This universal lack of production expertise is the fundamental factor constraining agricultural development.

A priority program in agricultural research and extension is required as a foundation for developing and disseminating a sustainable high-yield crop production technology among farmers. High-yield production technology should be developed on commercial size fields through cooperative research-extension agreements with progressive local farmers, complemented with additional research on small plots. USDA specialists should be made available on two year assignments to provide additional technical support. This program should receive $5-10 million in funding over five years.

TABLE OF CONTENTS

INTRODUCTION AND SETTING ....
- Geographic Focus
- Focus of the Paper
- Climate
- Agricultural Setting
- Historical Perspective

SEMIARID AGRICULTURE PRODUCTION TECHNOLOGIES ....
- Water Supply: Puerto Rico
- Water Supply: St. Croix
- Gravity Irrigation: Puerto Rico
- Sprinkler Irrigation: Puerto Rico
- Drip Irrigation: Puerto Rico
- Drip Irrigation: St. Croix

POTENTIAL NEW TECHNOLOGIES...
- Conjunctive Use of Surface and Groundwater
- Flexible Irrigation Delivery Schedules
- Flexible Cropping
- Wastewater Utilization for Irrigation or Aquifer Recharge
- Water Catchments
- New Crops
- Improved Irrigation Techniques
- Aquaculture
- Hydroponics

MARKETING...

RESEARCH AND EXTENSION..

STRATEGIES FOR IMPROVING SEMI-ARID AGRICULTURE PRODUCTION TECHNOLOGY...
- Puerto Rico
- U.S. Virgin Islands
- Summary

SUMMARY: CONSTRAINTS AND OPPORTUNITIES ....
- Principal Constraints
- Principal Opportunities
- Appropriate Congressional Objectives
- Federal Programs
- Recommended Actions to Mitigate Production Constraints
- Expected Consequences of Recommended Actions

Assessment of Semiarid Agricultural Production Technologies for the U.S. Affiliated Caribbean Islands

by:

Gregory L. Morris and Douglas J. Pool

INTRODUCTION AND SETTING

Geographic Focus. The semi-arid zone comprises the south coastal plain of Puerto Rico (Figure 1), Puerto Rico's two inhabited offshore islands (Vieques and Culebra), plus the three islands comprising the U.S. Virgin Islands (St. Croix, St. Thomas and St. John).

This paper focuses exclusively on the south coast of Puerto Rico and on St. Croix in the U.S. Virgin Islands; soil and water resources are inadequate to support significant agricultural activity on other islands. Although only a portion of Puerto Rico falls in the semi-arid zone, this region encompasses the most significant expanse of flat, mechanizable and adequately drained soils on the island, and is considered an area of long term agricultural potential (Vicente-Chandler et al, 1978; Tahal, 1984).

Focus of the Paper. This paper reflects many of the lessons learned by the authors in over a decade of combined experience in commercial agriculture in Puerto Rico, primarily in the island's semi-arid zone. The authors seek to accurately reflect the difficult reality of commercial agriculture in the semi-arid zone.

Climate. Climatic characteristics of the U.S. Caribbean have been summarized by Calvesbert (1970). The insular climate is strongly modified by the surrounding warm oceanic waters, which exhibit little seasonal temperature variation. As a result there is little diurnal or seasonal variation in temperature on the islands. The temperature averages about 80 degrees F during the hottest month and 75 degrees F during the coldest month, with a diurnal range of about 10 degrees. Trade winds blow regularly from an easterly direction, attaining mean maximum velocities of 10-15 mph (miles per hour) during the middle of the day, and reducing to 3-5 mph around midnight.

Annual rainfall in the semi-arid zone averages 30-50 inches, or about half the pan evaporation of 70-80 inches/year (Figure 2). Irrigation is required for the economic production of virtually all crops in the semi-arid zone. The relative humidity is high, averaging 80 percent over the course of the year.

Year-around warm temperatures, the small diurnal range in temperature, and consistently high humidity are important factors making growing conditions in the Caribbean markedly different from semi-arid regions on the U.S. mainland. This complicates the transfer of pest control and other environment-sensitive crop production technologies from the mainland to the islands.

Agricultural Setting. The structure of the agricultural sector in the Caribbean semi-arid zone differ dramatically from semi-arid zones on the U.S. mainland. One of the most important differences is the small scale of the Caribbean agricultural sector.

TABLE 1: SUMMARY CHARACTERISTICS OF THE AGRICULTURAL SECTOR IN THE SEMI-ARID ZONE OF THE U.S. CARIBBEAN (1982 Census of Agriculture).

	Puerto Rico Semi-Arid zone (a)	U.S. Virgin Islands
Number of Cropland Farms (b)	2,129	233
Acres (b)	77,077 (c)	819 (d)
Value of Production (b)	$40,717,000	$447,000
Avg. Value per Farm (e)	$19,125	$1,920

(a) Includes the following municipalities: Arroyo, Cabo Rojo, Guánica, Guayama, Guayanilla, Juana Díaz, Lajas, Patillas, Peñuelas, Ponce, Salinas, Santa Isabel, Yauco.

(b) Field, forage & vegetable crops, fruits & nuts, ornamentals. In Puerto Rico most of this acreage is irrigated; in the Virgin Islands most is not irrigated.

(c) Farms and cultivated cropland, 1982 Census of Agriculture for Puerto Rico.

(d) Acres harvested, 1982 Census of Agriculture for Virgin Islands.

(e) Computed as "Value of Production" divided by "Number of Cropland Farms". For comparison, the average cash receipts per farm in the 17 western states averaged $55,000 (Office of Technology Assessment, 1983).

Puerto Rico has about 50 times the land area and 100 times the population of St. Croix. The value of production on Puerto Rico's semi-arid south coast zone is nearly 100 times larger than the entire agricultural sector of the U.S. Virgin Islands (Table 1).

The semi-arid zone contains Puerto Rico's most sophisticated and mechanized farming operations. The 1982 Census of Agriculture reported 257 farms in the semi-arid zone using a total of 589 tractors, but these data include tractor use related to dairy and livestock operations. It has been casually estimated that there are approximately 100 private farmers using tractors on irrigated lands, with about half of these producing sugarcane (Meyer, personal communication, 7/9/85).

Commercial farm size on Puerto Rico's south coast varies from about 25-2,000 acres (Table 2).

TABLE 2: CHARACTERISTICS OF CULTIVATED FARMS AND CULTIVATED CROPLAND IN THE SEMI-ARID ZONE OF PUERTO RICO (Census of Agriculture, 1982).

Farm Size (acres)	Number of Farms	Area (acres)	Percent of Total Area
0 - 10	1,391	5,398	7 %
10 - 49	523	10,295	13
50 - 99	75	5,908	8
100 - 259	69	10,874	14
over 260	71	44,602	58

Cattle production on rainfed range is an important enterprise in the semi-arid zone. There is adequate water available for livestock watering but there appears to be limited economic potential for irrigated pasture. Accordingly, this paper does not address the livestock industry aside from suggesting the potential to produce grain and forage crops.

Eighty percent of the harvested acreage reported for the U.S. Virgin Islands occurs on St. Croix. Most of the acreage reported in the Census of Agriculture is not irrigated, and no irrigation data are reported in the census for the U.S. Virgin Islands. The small size of most farms in the Virgin Islands is illustrated in Tables 1 and 3. In addition to these row crops, the 1982 Census of Agriculture reported 603 acres of fruit trees (both bearing and non-bearing) on 218 farms, which produced an income of $152,000. From interviews with agricultural extension agents and farm visits, it is apparent that fruit and vegetable production is under-estimated in the U.S. Virgin Islands since backyard gardens are not included in the census data (John Matuszak, personal communication, Sept.1985).

TABLE 3: PRODUCTION OF ROW CROPS IN THE U.S. VIRGIN ISLANDS, (1982 Census of Agriculture).

	Number of Farms	Total Acres	Average Acres per Farm (a)
Cassava	46	18	0.4
Dry beans	24	4	0.2
Dry corn	25	6	0.2
Sweet potatoes	39	10	0.3
Taniers	11	2	0.2
Yams	25	6	0.2
Sorghum (forage)	3	403	134
Cabbage	8	2	0.2
Carrots	6	2	0.3
Celery	4	4	1.0
Cucumber	20	7	0.4
Eggplant	24	4	0.2
Green beans	8	2	0.3
Lettuce	7	2	0.3
Okra	27	8	0.3
Onions	5	8	1.6
Peppers	22	5	0.2
Spinach	5	2	0.4
Squash	10	2	0.2
Tomatoes	23	8	0.3
Other vegs.	7	8	1.1

(a) Computed by dividing "Total Acres" by "Number of Farms".

Extension personnel in St. Croix (Peterson, Buzdugan, personal communication, 7/8/85) estimate that there are approximately a dozen commercial farms which operate on a regular basis. These farms, which use irrigation, vary from about 1-4 acres in size. During rainy years more than 50 additional "backyard" gardens may be planted, some attaining 1-2 acres in size. Only two or three farmers in St. Croix derive their entire income from agricultural earnings (Peterson, personal communication, 7/8/85).

Several families of French descent operate spice plots of less than one-half acre in size at several sites on St. Thomas. According to Matuszak (1985):

> *"The spice farms of St Thomas produce a wide array of native seasoning and tea bush and provide fresh herbs to the many fine restaurants specializing in exotic cusine. These products are also shipped regularly to consumers in St. Croix and Tortola. Herb growers have extensive stands of rosemary, marjoram, and anise. Recently these commercial farmers have suffered extensive losses to root fungi in both rosemary and thyme. The Cooperative Extension Service is conducting trials to try and find a solution to this problem. St. Thomas spice farms plant a wide diversity of crops, a practice which decreases both pest infestations and economic risk. Crops include tea bush, inflamation bush, and plants used for both tea and seasoning like basil, mint, peppermint, and sweet scent. These herbs and others like tarragon, parsley, dill are sold to many of the St. Thomas restaurants, which rank among the best in the world."*

Historical Perspective. Sugarcane was essentially the only crop grown in the semi-arid zone of the U.S. Caribbean from 1900 until the 1960s. Cane production peaked in Puerto Rico in 1954 and continues today on a greatly reduced scale. During the early 1970s about 50,000 acres of sugarcane received irrigation on Puerto Rico's south coast (Morris, 1979), but sugarcane acreage has declined greatly since then despite local government subsidies[1].

In St. Croix sugarcane cultivation reached 18,100 acres during the 1920s (V.I.Experiment Sta., 1932), but very little of this received irrigation. Sugarcane cultivation became unprofitable and was abandoned on St. Croix in 1966.

---

[1] There are currently approximately 950 farmers engaged in sugarcane farming in Puerto Rico on approximately 60,000 acres. An additional 8,000 to 10,000 are farmed by the Puerto Rico Sugar Corporation, a subsidiary of the Puerto Rico Dept. of Agriculture. These farmers are guaranteed a price of $25/hundredweight of sugar, about $6/hundredweight above the domestic (US) price. These local subsidies are paid by the Agricultural Development Administration (AFDA), a subsidiary of the P.R. Dept. of Agriculture (Borrero, personal communication, 3/16/86).

Commercial farmers have found no profit-producing crop or combination of crops to replace large acreages of sugarcane in the semi-arid zone, and agricultural activity in the semi-arid zone has declined dramatically. Table 4 indicates that over 11,000 acres (21%) of the land irrigated in Puerto Rico in 1978 was no longer in production only four years later.

TABLE 4: DECLINE IN ACREAGE UNDER IRRIGATION IN PUERTO RICO (1982 Census of Agriculture).

Source of Irrigation	Acreage Under Irrigation	
	1978 census	1982 census
Public systems (reservoirs)	30,745	16,011
Private systems (wells, streams)	23,038	26,472
TOTAL	53,782	42,483

The non-sugar crops which are presently being produced on a limited acreage, and which are recognized by commercial farmers as being generally profitable, include: plantains, pigeon pea, sweet potato, eggplant, calabaza, cabbage, and banana. All these crops are grown for local market and many face stiff market competition from producers elsewhere in Puerto Rico or other low-wage islands. The pigeon pea, for example, has seen declining prices for several years due to competition from imports from the Dominican Republic, and at today's price is no longer profitable. The 1985 acreage of all these crops in the semi-arid zone probably does not exceed 5,000 acres. Under present market conditions the potential to substantially expand the acreage of these crops is limited.

The two Israeli-managed vegetable farms focus on the seasonal production of honewdew melon, peppers and tomatoes on about 4,000 acres and appear to have achieved profitable levels of production on these crops. Several other Israeli-managed farms are producing mango for export (Table 5). Several other local farmers have planted grain sorghum this year and one local farmer is producing rice, but it is too early to determine whether these will be profitable.

TABLE 5: SUMMARY CHARACTERISTICS OF ISRAELI-MANAGED FARMS IN PUERTO RICO (Data provided by each farm and compiled by authors).

Name of Farm	Year Established	Principal Crops	Area Under Drip Irrigation (acres)
ISPRAC (a)	1978	vegetables (d) mango	1,703
April (b)	1979	vegetables (d)	2,332
HDC (c)	1981	mango	600
Fruits International	1982	mango papaya	375

NOTES: (a) Israel Puerto Rico Agricultural Corporation.
(b) April Agro Industries and associated subsidiaries.
(c) Huertos del Caribe.
(d) Principal vegetable crops include honeydew melons, tomatoes and cubanelle peppers.

Crops which have been grown at least once on commercial scale fields in the semi-arid zone, but which are not currently considered profitable by commercial growers due to either production or marketing problems include: onions, watermelon, cantaloupe, cotton, summer and winter squash, sweet corn, okra, dry and green beans, papaya, potatoes, lettuce, cucumber, alfalfa, avocado and Tahiti limes. Tahal (1984) considered that many of these same crops have considerable future potential once the appropriate production technology is developed and tailored to local conditions.

SEMIARID AGRICULTURE PRODUCTION TECHNOLOGIES

Existing production technology focuses on the irrigation of field crops. Two fundamental aspects of irrigation technology will be discussed: (1) water supplies and (2) water application systems.

Naturally saline soils occur in some locations on the south coast of Puerto Rico. For example, the Teresa Clay soil series has a high salt content throughout its profile and is found in some locations more than a mile inland from the ocean. Attempts to plant sugarcane on this soil have failed and the soil is considered to have no agricultural value (USDA, 1979). Saline soils are also found in low-lying areas near the ocean both in Puerto Rico and the U.S. Virgin Islands and are often associated with mangrove vegetation or salt flats inland of mangrove areas. Some of these areas have historically been used for the evaporation of seawater salt.

However, salinity is not recognized as a problem on irrigated soils. Soil salinization is avoided because rainfall (averaging about 35 inches/year) is adequate to flush salts from the topsoil. In 12 years of working in this area the authors have not encountered significant soil salinization problems resulting from irrigation. Although the formation of minor salt accumulations has been observed in some fields where drip irrigation is being used, flushing by rainfall has been adequate to prevent this accumulation from reaching excessive levels.

Drainage is not a problem in most areas; only in some areas of low-lying soils near the coast is the water table so high that drainage becomes a problem. However, because the water table near the coast is very close to sea level, little improvement can be achieved through the construction of gravity drainage works. In some of these coastal areas high water tables are associated with saline soils thereby rendering the soil unfit for agriculture.

Tailwater disposal is also not a problem. In traditional irrigation practice little tailwater is generated, and tailwater from drip irrigation is zero. Where they occur, tailwaters are simply diverted into a drainage ditch where they either percolates back into the aquifer or flow to the ocean.

Gravity and sprinkler systems have been the principal types of irrigation used in Puerto Rico, which has a relative abundance of water as a consequence of runoff from high-rainfall areas in the mountainous upper watersheds. Due to inadequate water supplies in the U.S. Virgin Islands gravity or sprinkler irrigation is used rarely. Drip irrigation is used on both islands.

Water Supply: Puerto Rico

Sources of irrigation supply. Irrigation water supplies are derived from three principal sources: reservoirs, groundwater and stream diversions (Table 6). The importance of reservoirs is greater than suggested by Table 6 because about 40% of the surface water recharges the aquifer and is later re-used as groundwater supply (and thus double-counted). For example, in the 14,000 acre area serviced by the Guayabal reservoir, 70% of all irrigation supply is derived from the reservoir; 40% is applied directly and 30% is supplied via groundwater recharge which is subsequently pumped from irrigation wells (Morris, 1985).

TABLE 6: WATER SUPPLIES FOR IRRIGATION AVAILABLE NINE OUT OF TEN YEARS ON THE SOUTH COAST OF PUERTO RICO FOR MID-1970s PATTERN OF WATER UTILIZATION. LESSER SUPPLIES WILL BE AVAILABLE DURING A DROUGHT EVENT WITH A RETURN INTERVAL OF ONCE IN 10 YEARS. (Morris, 1979)

Source	Volume (acre-feet/year)
Irrigation Reservoirs	69,000
Groundwater (private wells)	145,000 (a)
Streamflow (private stream diversions)	14,700

(a) Includes recharge derived from deliveries from reservoirs and stream diversions, plus a significant but temporary reduction in groundwater storage.

Stream diversions have been used for irrigation supply in Puerto Rico for centuries, and gravity irrigation using stream diversions has constituted a principal source of groundwater recharge in some local areas. However, few stream diversions remain in use today. Stream diversions have been abandoned because the land has been withdrawn from agricultural production for reasons other than water availability. The stream diversions which have been withdrawn from service could be rehabilitated with little effort.

Declining supplies from reservoirs. The principal water supply problem facing Puerto Rico is the deterioration in service from the irrigation districts which serve approximately 40,000 acres. Deliveries from the irrigation districts have fallen below half of their pre-1920 design capacity of four inches per month to the serviced lands and continue declining due to the following factors: archaic operating rules designed to service a sugarcane monoculture which no longer exists, reduced irrigation demand, and continuing reservoir sedimentation. Declining surface water availability has led many farmers to rely exclusively on groundwater supplies. Because deliveries from irrigation district reservoirs constitute the single most important source of groundwater recharge, this trend of changing irrigation water use will eventually cause an unfavorable groundwater balance and the intrusion of saline seawater into the freshwater aquifer (Morris, 1985). No action has yet been taken to manage the surface water system to insure that adequate amounts of recharge are provided.

Rigid irrigation delivery schedules. The sugarcane monoculture is being replaced by a variety of crops including high-value perennials such as bananas and fruit trees, low-value perennials such as forage, high-value annuals such as winter vegetables (tomatoes, melons) and low-value annuals such as pumpkin and pigeon peas. The irrigation demand of non-sugar crops varies from zero (land in fallow) to a maximum of about 2 inches/week. Because irrigation district rules include no provisions for seasonal irrigation deliveries and provide inadequate flows for periods of peak water demand, the irrigation districts do not constitute a reliable source of irrigation supply for many crops due to the constraints imposed by district operating rules rather than inadequate volumes of water supply. A complete re-structuring of the operation of the two irrigation districts on the south coast is the key to insuring substantial quantities of irrigation water for the future. Failure to remedy this situation will result in reduced irrigation supplies, in some areas to as little as one-third of historical levels (Morris, 1985).

Excessive spillage and wasteage of irrigation supplies. Irrigation reservoirs in Puerto Rico are relatively small in relation to the annual runoff; reservoir capacity is inadequate to permit the carryover of water in storage from a wet year to a dry year. Consequently, in the production of sugarcane with its 12-month irrigation season, acreages were planted based on the volume of irrigation supply which can be made available in most years. Consequently, in years of average or above-average rainfall large volumes of water are spilled from reservoirs because inadequate acreage has been planted to use all the available irrigation supply.

However, with the conversion from sugarcane to short cycle crops having an irrigation season of less than 100 days, it becomes possible to implement a "flexible cropping" system, as discussed subsequently in this paper.

Water Supply: St. Croix

Irrigation supplies on St. Croix are presently obtained from small wells. Of a total fresh groundwater resource estimated at 3.9 million gallons per day, in the mid-1960s only 200,000 gallons per day was being used for agricultural purposes, all of this at sugar mills and on sugarcane plantations (Jordan, 1975). Agricultural water use has diminished considerably since sugarcane production ceased.

Stream diversions were an important source of irrigation supply during the early part of the 20th century when deforestation of the upper watersheds caused streamflow to increase above natural levels. However, with reduced land use pressure and resultant natural reforestation of the watersheds, the streams have dried up and now flow only in response to significant rainstorms (Jordan, 1975). Thus, stream diversions in St. Croix have been abandoned for lack of water.

Winter (November-April) is the optimum production season both climatically and from a marketing standpoint (high price for imported produce plus high local demand from tourists). A winter growing season is also optimal from the water supply standpoint since it immediately follows the wet season. This enhances the feasibility of using impoundments to capture wet season runoff (August-November) for winter season irrigation supply.

Several earthen impoundments were once used to supply irrigation for sugarcane on St. Croix. Though no longer in use, rehabilitation may be feasible to supply the Harvey Land area on St. Croix, an agricultural park sponsored by the local government but which lacks irrigation. The technical and economic feasibility of this strategy has not been examined.

Gravity Irrigation: Puerto Rico

Technology Description & Application: Gravity (furrow) irrigation, the traditional sugarcane irrigation system, remains the principal system in use and probably accounts for two-thirds of the irrigated acreage. The principal crops grown under gravity irrigation include sugarcane, plantains, pumpkin, pigeon peas and limited truck crops. Water supplies are obtained from both surface and groundwater sources.

Gravity irrigation is typically used on smaller and medium-size family farms (up to a few hundred acres) which lack the capital resources to install improved irrigation systems. Typically a flow of 2-3 cfs is diverted into a field from a well or ditch and is turned into individual furrows by an irrigator with a shovel.

Techniques to improve the efficiency of gravity irrigation have been applied only intermittently on a few farms. For example, siphon tubes and gated pipe systems have both been used on one or two farms. Land planes were formerly used by sugar companies, but are no longer used. Precision leveling has been conducted on an experimental basis (although several thousand acres have been precision leveled elsewhere on the island for rice cultivation). However, even though improved gravity irrigation systems worked well, these farms have not been profitable and this has discouraged emulation.

The major factor limiting the use of improved gravity irrigation system is the required capital investment coupled with the perceived lack of economic return. There is a general impression among farmers and local government officials alike that, dollar for dollar, limited capital would be better spent on drip irrigation rather than on improved gravity systems. Nonetheless, a variety of field crops are entirely unsuited for drip irrigation (eg. drip irrigation is too costly to use on low value crops and it is entirely unsuited for forage crops because they are not planted in rows). Improved gravity irrigation represents desirable technological alternative in these cases.

Implementation Impacts. While gravity irrigation is viewed as being "inefficient" in its use of water, in Puerto Rico this is not necessarily true from the hydrologic viewpoint. In most areas excess irrigation applications simply provide groundwater recharge which is subsequently recaptured by irrigation wells; this "inefficiency" does not have an adverse effect on the hydrologic system. In fact, improving irrigation efficiency can decrease groundwater recharge and thereby increase the threat of seawater intrusion into the aquifer. This apparent paradox is explained below.

Saline intrusion into coastal aquifers is caused by excessive net withdrawals of fresh water which causes lowered groundwater levels. The general relationship a reduction in fresh water levels and resultant saline intrusion is well known and is often described using the hydrostatic Gyhben-Herzberg relation (Freeze and Cherry, 1979). The intrusion of salt water into fresh water aquifers due to overpumping (from a municipal well) has been documented previously in Puerto Rico by Adolphson et. al. (1977). An net increase in the extraction of fresh water in a coastal aquifer produces an inland movement of the salt-fresh water interface, a process known as saline intrusion. Saline intrusion occurs naturally, and in fact accompanies all groundwater extraction from coastal aquifers. Saline intrusion becomes a problem when it becomes "excessive", contaminating operational wells with salt water.

At first it would appear that an increase in irrigation efficiency would decrease pumping requirements and thereby reduce net groundwater withdrawals. However, under conditions in Puerto Rico this is not the case. On Puerto Rico's south coast the only net loss of water from the hydrologic system caused by irrigation is due to evapotranspiration. Any change in irrigation practice (eg. a change in pumping rate) which does not alter the rate of evapotranspiration (ET) will have no effect on the groundwater balance. In Puerto Rico, the water pumped for irrigation which is not evaporated simply infiltrates back into the aquifer. Thus, a change in pumping rate will not necessarily alter the net withdrawal of fresh water; this is determined by the difference between pumping and recharge, with the difference term being ET.

The large effect that groundwater pumping and evapotranspiration from irrigated areas has on the south coast's groundwater budget has been documented in studies by the USGS, undertaken when large areas of sugarcane were irrigated. The infiltration of excess irrigation water has historically provided a greater volume of groundwater recharge than has rainfall along most of Puerto Rico's south coast (Giusti, 1968; Giusti, 1971; McClymonds and Díaz, 1972).

Inefficient irrigation in Puerto Rico has two adverse effects: (1) pumping costs are excessive because more water is pumped than is necessary; and (2) crop yields are reduced because irrigation is not applied at the optimum frequency and applications are not uniform, resulting in moisture stress to part or all of the irrigated field. This moisture stress results in a decrease in transpiration and a corresponding decrease in plant production.

An increase in irrigation efficiency which increases production by reducing the incidence of moisture stress must necessarily produce an increase in transpiration. It is this increase in transpiration that causes the increase in net withdrawals from the aquifer, since evaporation plus transpiration is the only net loss from the hydrologic system caused by irrigation. Thus, assuming that acreage irrigated and other factors remain unchanged, an increase in efficiency will increase net groundwater withdrawals and produce a corresponding increase in saline intrusion.

Sprinkler Irrigation: Puerto Rico

Technology Description & Application. Sprinkler irrigation was used first on sugarcane in the 1960s and since then has been used on forage, many vegetable crops and irrigated pasture. Sprinkler irrigation is the least-used type of irrigation system, being used primarily on small to medium size farms which lack capital resources to install drip irrigation, which produce crops unsuited to drip irrigation, or where topography does not permit gravity irrigation.

Several factors have historically impeded the more widespread use of sprinkler irrigation and will continue to impede its use in the forseeable future.

1. The prevailing tradewinds disrupts sprinkler pattern, making it preferrable to irrigate at night. Night irrigation is viewed as both inconvenient and costly because it requires a full time irrigator to perform the part-time task of monitoring the pump, cleaning trash from the pump intake, etc.
2. Soils in many areas are both sticky and slippery, greatly reducing the utility of travelling and portable sprinkler systems on row crops.
3. The wetting of the foilage and fruits promotes conditions favorable for diseases.

Side-roll and center-pivot systems are generally unsuited for use in Puerto Rico because of the small field sizes (5-50 acres), irregular field shapes, and a multitude of obstructions in agricultural areas including roads, ditches, canals, ponds, railroad embankments, power lines, houses, etc.

Implementation Impacts. Although sprinkler irrigation can be used advantageously on some low-value crops and on sloping soils, in general it is not the favored irrigation technique. If irrigation efficiency is increased by using sprinkler irrigation, groundwater recharge will be diminished.

Drip Irrigation: Puerto Rico

Technology Description & Application. Drip irrigation, first used commercially in Puerto Rico in 1974 by Richard Yero, a local vegetable farmer, has grown in popularity and is now considered the irrigation system of choice for high value vegetable and tree crops. Drip irrigation offers the following important advantages as compared to gravity and sprinkler techniques:

1. Uniform application of water on fields of irregular shape and topography, the field configuration frequently encountered in Puerto Rico.

2. In the semi-arid zone the weed seed reservoir is immense and the weed species are naturally adapted to extremely rapid growth. As a result, the application of irrigation results in severe weed competition. Because only a portion of the topsoil is wetted using drip irrigation, fewer weeds germinate and weed control is greatly facilitated.

3. Irrigation can be applied uniformly in precise amounts, limiting water use and pumping cost to only that quantity required by the crop.

4. Optimum soil moisture and nutrient levels can be maintained.

5. Drip irrigation does not produce muddied furrows which interfere with cultural practices and harvest, does not wet foilage and fruit thereby promoting disease, and does not wash off or dilute foliar pesticides.

Despite these important advantages, drip irrigation does not represent a panacea to irrigation needs. Some crops cannot be grown under drip irrigation for agronomic or economic reasons. For example, drip irrigation is unsuitable for germinating onion seed because it does not provide uniform wetting to the uppermost layer of soil (sprinkler or gravity irrigation is used instead). Drip irrigation is also unsuited for forage crops or field crops such as pigeon peas which have a low income per acre. It is also the most costly of all irrigation systems, with installation costs running $1,500 to $2,000 per acre on typical farms in Puerto Rico (Goyal, 1984).

Most importantly, the use of drip irrigation by itself does not guarantee high yields. A drip irrigation system is only one part of the overal crop management system. The full benefits of drip irrigation can be achieved only when combined with programs of soil fertility, pest control and other cultural and post-harvest practices which match the sophistication of the irrigation system.

Approximately 6,000 acres of drip irrigation are already installed in Puerto Rico, mostly on heavily capitalized Israeli-managed corporate farms producing either vegetables or mangos. Drip irrigation is presently installed on less than a dozen non-Israeli farms, with the largest of these having approximately 50 acres installed on bananas.

The high cost of installation, high production costs and high degree of risk associated with high-value crops are the greatest barriers to more widespread use. For example, it can easily cost $5,000 per acre[2] to install irrigation and bring the first crop into production. Thus, on a 100 acre farm the total investment at risk would be on the order of $1/2 million. Investments of this nature are considered to have high risk due to a variety of factors.

1. The fact that the quantity and quality of production is dependent on the weather.
2. The relatively limited extent of favorable local experience in the production of high-value crops and the general lack of local experience with these crops contributes to risk.
3. Uncertainty concerning future market prices plus the local history of problems associated with penetration of the mainland market adds significantly to the element of risk.

That a number of agricultural ventures have been initiated during the past decade, but relatively few have been economically successful, further suggests that agricultural enterprises are generally high-risk investments. The highly-publicized failure of the Israeli firms to repay their debts, plus the uncertainty surrounding the government-sponsored rice program, only adds to the perceived level of risk.

---

[2] $2,000 for the irrigation system and $3,000 for the crop. The irrigation system should have a life of about 15 years. Annual maintenance costs for the irrigation system should run about $250/acre.

Nearly 4,000 acres of drip irrigation have been installed on two Israeli vegetable farms. These two farms, financed by the Commonwealth government, represent the showcase of drip irrigation and new agricultural production technology for Puerto Rico. Despite the poor economic performance of these farms to date due to high start-up costs, marketing problems and low yields during the first years of production, these two large vegetable farms have achieved very high yields of quality produce (tomatoes, peppers, honeydew melons). This has led farmers view drip irrigation technology as the best method for achieving profitable levels of production on high-value crops.

To date neither the agronomic techniques developed on the Israeli farms, nor the required irrigation infrastructure, has been available to other farmers. Although the Israeli farms can receive research and extension support from the Department of Agriculture they have opted to develop their own techniques, apparently due to the inadequacy and poor quality of the research and extension assistance available. For example, in 1978 (when the first Israeli firm was established) neither the Experiment Station nor the Extension Service had any prior experience using drip irrigation on vegetable crops, their variety trials and other basic research had not been conducted using drip irrigation. Obviously, under this condition it was not possible to gain much useful information from the research and extension program.

Since this time the Israeli farms have developed complete technological packages for production of various vegetable crops, and have conducted numerous variety and other trials. However, in large part these were not conducted as cooperative projects with the Department of Agriculture, and the Israeli firms have not released to the public sector the information they have developed. They are unwilling to release details of their crop management practices unless compensated by the government for the "research" expenses which they incurred in developing this information (Sánchez, personal communication, 7/9/85).

The government made preliminary plans to install 50 acres of drip irrigation on each of approximately 10 family farms operating on state-owned lands (Sánchez, personal communication, 7/9/85). However, no concrete action has been taken in that direction to date and there is no assurance that these systems will be installed.

Implementation Impacts. Drip irrigation is widely recognized as being a water-conserving technology because it can uniformly deliver the exact amount of water required for growth, regardless of topography or field configuration. In contrast, water cannot be applied as uniformly using gravity and sprinkler irrigation, making it necessary to apply excess irrigation water to insure that the entire field has received adequate moisture. In Puerto Rico the excess water applied typically percolates beyond the crop root zone, thereby recharging the aquifer.

In the 20,000 acre Lajas Valley the groundwater is saline and is not recommended for irrigation (Vásquez and Vélez, 1967). Water conservation may be realized by using drip irrigation in this area. However, elsewhere on Puerto Rico's south coast water-conservation cannot be achieved using drip irrigation because the use of drip irrigation will sustain crop consumptive use at high levels while eliminating the groundwater recharge that accompanies "inefficient" gravity irrigation. This is explained below, as summarized from Morris (1985).

Under the discussion of implementation impacts of gravity irrigation it was shown that an increase in irrigation efficiency can, by itself, result in reduced groundwater recharge. The substantial increase in irrigation efficiency possible using drip irrigation is one factor which will tend to increase net withdrawals from the aquifer, thereby promoting saline intrusion. However, in the case of drip irrigation there are other factors at work as well.

Drip irrigation systems require high purity water, and accordingly surface waters are rarely used as drip irrigation supply in Puerto Rico. As a result, in the conversion from gravity to drip irrigation the imported surface water supplies (which provided the recharge under the "inefficient" gravity irrigation system) are typically abandoned and replaced with highly efficient drip irrigation systems supplied from wells (which provide little recharge and zero water imports). Another important factor which inhibits the use of surface water for drip irrigation is its uncertain availability, since surface water supplies are heavily over-subscribed.

Several strategies might be used to insure adequate groundwater recharge, all of them based on continuing the importation of surface water to augment natural recharge from rainfall and streamflow. However, institutional impediments must be resolved in order to implement a system to maintain groundwater recharge. To date Commonwealth agencies have shown little willingness to addressing the institutional changes required to apportion the available surface water resources in a manner which will guarantee adequate groundwater recharge.

In addition to the problem of an unfavorable groundwater balance which would be caused by the large scale implementation of drip irrigation, the relative incompatibility of drip and gravity irrigation systems is another factor which potentially inhibits implementation.

Most drip irrigation systems make it difficult or uneconomical to gravity irrigate the same field due to incompatible pumping requirements; drip irrigation requires a lower volume and higher pressure than a gravity system. Without careful design the installation of drip irrigation will sharply limit crop rotation alternatives. At present low-value crops are not used as rotation on drip irrigated fields, and drip irrigated fields used for the production of annuals are planted only during the winter season.

For several years bi-wall (disposable) dripper lines were used in Puerto Rico, but all drip irrigation systems installed now use in-line (re-usable) dripper line. The in-line dripper tube has been favored because, despite its higher initial cost, it is perceived as a better long-term investment and is less susceptible to clogging under local conditions. There has also been prior experience in Puerto Rico using "lay-flat" (plastic) tubing and portable aluminum pipe to convey water to drip systems, but because of mechanical damage and the deterioration of "lay-flat" tubing on prolonged exposure to sunlight, buried distribution systems are preferred despite the higher initial cost. Automated irrigation systems have been plagued with operation and maintenance problems and are currently not recommended.

Drip Irrigation: St. Croix

Technology Description and Application. Aside from the livestock industry, the agricultural sector in St. Croix may be divided into two general groups: commercial and backyard. The commercial growers, estimated to number less than 20, have adequate capital to install drip irrigation on anywhere from one to four acres. The backyard growers, numbering perhaps 100, do not have irrigation and plant during wet years. Bi-wall dripper line is universally used in St. Croix (Peterson and Buzdugan, personal communication, 7/8/85).

Extension personnel estimate that only two or three commercial growers are able to earn their entire livelihood from agriculture (Peterson, personal communication, 7/8/85). One of these, St. Croix Produce, Inc. (husband, wife, two employees), has 1.5 acres under drip irrigation and focuses on crops which earn the highest value in the local market (tomatoes, cucumbers, pepper, squash, eggplant, bananas, etc.), with their year-around moneymaker being tomatoes. Excess or damaged produce is fed to hogs which are confined for fattening. Produce is retailed direct from a produce stand attached to the house. To provide a sampling of July prices, choice vine-ripe tomatoes retail at $1.50/lb and cucumbers at $0.80/lb.

Implementation Impacts. Due to extreme water scarcity, drip irrigation is recommended for use in St. Croix. Sprinkler irrigation should be used only on specific crops where drip irrigation is unsuitable. However, the extent of the area which can be irrigated, even seasonally, is sharply limited by water supply. Assuming it is possible to develop a total agricultural water supply of 500 acre-feet per year (450,000 gal./day) from groundwater and surface impoundment, this is adequate for the year-around irrigation of only 125 acres (or seasonal irrigation on greater acreage).

POTENTIAL NEW TECHNOLOGIES

As noted in foregoing discussions, the surface water reservoirs operated by the irrigation districts in Puerto Rico provide approximately two-thirds of all irrigation supply, either through direct deliveries or indirectly by recharging groundwater aquifers tapped by irrigation wells. Deliveries from reservoirs operated by the irrigation districts is steadily declining, but there is no corresponding decline in groundwater withdrawals, a situation which makes seawater intrusion into the aquifer inevitable if remedial action is not taken. At the same time, the water available during wet years is spilled to the ocean due to the limited storage capacity available in reservoirs.

Three basic technologies, previously identified by the Office of Technology Assessment (1983), should be applied to increase the volume and utility of the existing irrigation supply infrastructure in Puerto Rico in the face of changing irrigation demands and the sedimentation of some reservoirs. These three technologies, which should be applied as an integrated package, include:

1. Conjunctive management of surface and groundwater resources,
2. Flexible Irrigation Delivery Schedules, and
3. Flexible Cropping.

Due to the high cost of additional infrastructure such as reservoirs, and the sharply constrained ability of local government and farmers to pay for costly new infrastructure, it is essential that strategies for improving irrigation systems in Puerto Rico focus on new low-cost operational strategies rather than high-cost infrastructure development. All three of the aforementioned technologies are oriented to optimizing the operation of existing infrastructure, making them economical and highly appropriate.

Though there are no existing irrigation systems in the Virgin Islands other than private single-farm systems, these same three fundamental technologies should be incorporated into any future irrigation infrastructure which is planned for the U.S. Virgin Islands.

Following the discussion of these three important technologies, several additional technologies are described which may be applicable to the U.S. Caribbean.

Conjunctive Use of Surface and Groundwater. Conjunctive management involves the management of both surface and groundwater resources as a complete hydrologic system, with the water manager manipulating the flows between these two hydrologic entities in order to increase the overall water yield. Conjunctive management represents an important departure from more traditional approachs in which surface and groundwater resources are managed separately, with little concern for the interaction between these two sources which occurs in the hydrologic environment or which can be induced through artificial recharge or other methods.

Conjunctive use is a water management technology which has not yet been applied in the U.S. Caribbean. However, application of this technology will be required in the future to preserve irrigation supplies on Puerto Rico's south coast in the face of declining deliveries from surface water reservoirs. Conjunctive use technology in Puerto Rico should focus on maximizing irrigation deliveries and aquifer recharge from surface water during wet periods when streamflow is large, and emphasizing groundwater withdrawals during drier periods. In this manner the aquifer can be used as an underground storage reservoir, replacing reservoir storage capacity which is being lost due to sedimentation.

Conjunctive use strategies may also be useful on a small scale in the Virgin Islands, but feasibility studies have not been made.

Flexible Irrigation Delivery Schedules. It is essential to undertake the conversion of Puerto Rico's irrigation districts from the year-around constant-rate delivery system designed to supply a sugarcane monoculture, to a system which incorporates the flexible delivery system required to service mixed crops. Under flexible scheduling a farmer is not assigned a specific and constant volume of irrigation water each month, but rather is able to adjust his irrigation use according to the seasonal demands of his crop(s). Furthermore, in the interest of water conservation the farmer should also be able to adjust his irrigation demand on a daily basis when the need for irrigation is reduced due to rainfall, etc.

While this technology is neither new nor technically difficult to implement, it is new in Puerto Rico and will require adjustment on the part of local institutions and farmers. One of the limitations which will be posed on the application of this technology in Puerto Rico is the limited conveyance capacity of existing infrastructure; this will limit delivery rates during months of high irrigation demand.

Any irrigation system designed for the Virgin Islands must include flexible irrigation scheduling as an integral part of its design.

Flexible Cropping. The term "flexible cropping" has been used by the Office of Technology Assessment (1983) principally in reference to dryland agriculture:

> *"In this system, a crop is planted when stored soil moisture and predicted rainfall are favorable for a satisfactory yield. When crop prospects are not favorable, no crop is planted, and a field is left fallow."*(p300)

However, in a modified form this concept is equally applicable to the scheduling of irrigated crops in the U.S. Caribbean. Due to high rates of evaporation compared to the capacity of the soil to retain moisture, stored soil moisture is rapidly depleted and cannot be counted as an important source of crop moisture. However, the concept of flexible cropping becomes feasible in the Caribbean by substituting the term "irrigation supplies" for "soil moisture" in the previous definition.

Because of limited reservoir capacity, streamflow from a wet year cannot be stored for use during a dry year. Furthermore, there is a technical limit to the amount and rate of artificial groundwater recharge which can be induced. As a result, it is not uncommon for large volumes of potential irrigation supply to be spilled to the ocean during years of average or above-average rainfall.

By carefully tracking reservoir and groundwater levels, and continuously updating predictions of expected future rainfall based on probability analysis, it should be possible to predict irrigation supplies for a period of several months into the future. When available plus expected supplies exceed a specified minimum value, farmers may be advised that they may expect an increased irrigation allottment during the upcoming months and irrigated acreage may be increased. Thus, during a year having average or above-average rainfall, additional acreage could be planted to take advantage of the additional irrigation supply. During drier periods the acreage would be reduced, plantings would be delayed, or rotation crops requiring less irrigation would be planted. This strategy maximizes the acreage under irrigation within the constraints imposed by the limited storage capacity of existing infrastructure. A technical and economic analysis of this strategy has not yet been undertaken.

Wastewater Utilization for Irrigation or Aquifer Recharge. Treated wastewater is not presently used as a source of irrigation supply on either St. Croix or Puerto Rico. There is little potential for the use of wastewater in St. Croix because the use of a saltwater flush system in some sewered areas imparts excessive salinity to wastewater (Green, personal communication, 7/8/85). However, it may be possible to blend inferior quality wastewater with impounded runoff to extend irrigation supplies.

In Puerto Rico it is feasible to use wastewater for irrigation supply via groundwater recharge (Heisel and Gonzalez, 1979), and some wastewater facilities plans call for the land disposal of some effluents via irrigation (Lizardi et.al. 1975). However, due to diminished irrigation demand the interest in making more water supplies available from wastewater has declined. Wastewater has not yet been used for either aquifer recharge or irrigation in Puerto Rico.

Water Catchments. A plastic-lined water catchment system has recently been demonstrated on St.Croix, where a $19,800 installation collects an average of 440,000 gallons annually from an area of one-half acre (Rakocy et.al., 1984). However, when this investment is amortized over 10 years, the cost of water is about $5/1000 gallons ($1,600/acre foot), or about 25-50 times more costly than groundwater. Water catchments are economically feasible only for high value activities such as aquaculture or hydroponics where water is completely re-circulated, and only on small islands where groundwater is undesirably saline. Artificial catchments are considered too costly for the economical irrigation of field crops.

New crops. Potential new crops that could be grown in semi-arid lands are limited by lack of market and competition from non-U.S. Caribbean islands that compete favorably on the basis of low wage costs. While the technology exists which will permit these same crops to be grown in the U.S. Caribbean, the production technology has not been refined to the point that profitable levels of yield can be achieved within the prevailing market structure.

Little potential is seen for the development of new or "exotic" crops for the U.S. Caribbean. Rather, limited resources are probably better spent on refining high-yield production technology on crops with which there is already some previous experience. For instance, inadequate work has been accomplished with respect to both plant breeding and variety trials, and mixed commercial results have been obtained using Hawaiian plant varieties in the Caribbean. Efforts need to focus on selection and development of varieties suited to local soils, climate and disease problems, and the development of high-yield production techniques suitable for achieving economic levels of yield in these crops.

The crops which hold the greatest potential for expansion are those with significant export or import-substitution potential. The fruit and vegetable crops that are currently produced (including tomatoes, honeydew melon, peppers) could probably be expanded and intensified through development and dissemination of improved production technology and additional market development effort. Increased attention should also be given to forage and grain production; the local local livestock industry (primarily dairy cattle and chickens) is an obvious but relatively untapped market.

Improved irrigation techniques. Advanced irrigation technology is already available in the Caribbean. What is lacking is expertise in integrated crop management practices in areas including variety selection, fertility, and pest and disease management which must be applied along with improved irrigation systems to achieve maximum yields. There exists no effective mechanism for refining and transferring this technology to farmers.

Aquaculture. Several commercial aquaculture operations have been established in the U.S. Caribbean over the past decade with mixed economic success. There appear to be no environmental constraints to preclude aquaculture activities in either humid or semi-arid zones, once other production and marketing problems are worked out.

In St. Croix the Agricultural Experiment Station is undertaking highly interesting research on a combined aquaculture-hydroponic system based on tilapia and tomatoes or lettuce (Rakocy, 1985). This system, which recirculates water captured from the previously mentioned rain catchment, appears to be highly pertinent to St. Croix, and from the technical standpoint could also be applied on the other islands not otherwise mentioned in this report (St. Thomas, St. John, Vieques and Culebra).

At the current state of development the fish culture technology is only marginally profitable, and the best hope for profitability lies in combining fish culture and hydroponic technologies (Barnaby and Busch, 1984; Rakocy, personal communication, 7/8/85). Marketing considerations will probably limit application of this technology to high-demand islands of St. Croix and St. Thomas where produce prices are high.

Hydroponics. There is only limited experience with hydroponics in the semi-arid zones of the U.S. Caribbean and few of these operations have been commercially successful. Most hydroponic operations prefer to locate at higher elevations (humid zones) where cooler temperatures extend the growing season for high value temperature-sensitive vegetables such as tomatoes, English cucumber and lettuce. Despite continuing initiatives in the U.S. Virgin Islands, mostly by U.S. mainalnd entrepreneurs, hydroponics is seen to have limited future potential in the hot semi-arid zone.

MARKETING

Puerto Rico. Farmers in the semi-arid zone are more advanced in their marketing strategies than farmers elsewhere on the island. However, only the heavily-capitalized Israeli farms operate modern export-oriented packing shed operations shipping to mainland and European markets. A few farmers operate smaller packing operations oriented toward the local market. Otherwise marketing techniques are much less advanced than mainland practice, with products suffering quality imperfections due to insect damage, poor or nonexistent grading, and post-harvest damage from inadequate packing, rough handling, lack of proper pre-cooling and refrigeration, etc. Tahal (1983) summarized the situation in the following terms (author's translation).

> *"The fundamental requirement for servicing export produce markets, or for substitution of imports, is to achieve reliable and high volume production, an appropriate pack, and above all, a high level of quality.*
>
> *"However, the existing agricultural production system does not possess the knowledge required to satisfy these requirements. Neither governmental nor private agricultural organizations, nor the Agricultural College, nor the Extension Service nor the Experimental Station possess professional personnel trained in modern commercialization.*
>
> *"In Puerto Rico obligatory regulations do not exist concerning norms for classification and packing of fresh fruits and vegetables. Regional packing centers are virtually unused. A gap has been created between the system of wholesale marketing, which has undergone rapid modernization during the past decades, and the production system, which has not developed in a parallel manner to serve the supply needs of the former."* (Appendix 5, p16).

While these constraints severely hinder the marketing of new crops, it has not greatly hindered the local marketing of many traditional crops such as plantain, banana, calabaza (pumpkin), malanga, sweet potato, citrus, and pineapple. However, some of these traditional crops are protected against competing imports by local regulations.

The local market, primarily supermarkets and small stores, has long been accustomed to local fruit of inferior appearance. Being a low income area, price is a more important factor than appearance and the wholesalers who deal in local produce are frequently unprepared to pay a premium for an improved pack. Because no farm on the island is more than 6 hours by truck from San Juan, the principal produce market, farmers typically harvest on one day and drive overnight to the market, thereby avoiding refrigeration. Also, many farms are too small to afford packing facilities, and there has been a notable lack of success in organizing successful marketing organizations such as cooperatives.

St. Croix. Aside from dairy products, there is virtually zero penetration of local supermarket sales by local producers. Locally-grown produce is retailed direct from the farm at roadside stands or in the traditional downtown open-air market, with limited sales to the restaurant trade. However, this should not be interpreted as a market failure but rather reflects the low volume, low quality, erratic and unreliable supply of local production. Gerber (1979) observed that:

> *"The key to development of a vegetable industry is the ability to grow large quantities of high quality vegetables... The present marketing system in the Virgin Islands could easily handle locally grown produce if it was available in any quantity."*

It should also be noted that most fruit and other produce are imported from growers in Puerto Rico or on the mainland, or from nearby low-wage islands (including Dominica, St. Lucia, St. Maarten, Martinique, Dominican Republic). Local producers have great difficulty competing economically against these imports from areas where production costs are considerably lower than in the Virgin Islands.

RESEARCH AND EXTENSION

Puerto Rico has a wide diversity of climate and crops and a focus on the semi-arid zone has been lacking, although it receives more attention now than previously. The growing (though still inadequate) research emphasis on non-sugar crops in the semi-arid zone is suggested by the published research. In 1981 only 5 of 49 articles in the University of P.R. Journal of Agriculture were applicable to arid zone crop production, but this had increased to 12 of 53 articles by 1984.

On St. Croix high yields of papaya, watermelon and tomato have been demonstrated experimentally (Buzdugan, personal communication, 7/8/85; College of Virgin Islands, 1982). However, technology transfer to farmers remains slow. Because of the extremely small size of the agricultural sector, plus the reduced geographic size of the island, communication between the Experiment Station and farmers is greatly facilitated on St. Croix as compared to Puerto Rico.

Most farmers in the U.S. Caribbean are unable to achieve high levels of yield. The most important single issue which research and extension must address is the achievement of high yields of quality product on commercial farms. If high levels of yield cannot be achieved, then the crop will be abandoned regardless of achievements in post-harvest, marketing or other areas.

Low yields are partly due to lack of infrastructure, such as drip irrigation equipment. However, providing drip irrigation does not solve the problem unless sophisticated crop management practices are simultaneously applied in areas such as soil fertility and pest and disease management. U.S. Most Caribbean farmers, researchers and extensionists (with a very few and notable exceptions) lack experience with this technology.

Because research and extension personnel rarely have appropriate prior experience with high yield technology (including production systems based on drip irrigation), they cannot effectively guide farmers. The current edition of the guide for commercial vegetable production in Puerto Rico ("Conjunto Technológico para la Producción de Hortalizas", Univ. of Puerto Rico, 1979) offers dramatic evidence of this lack of experience and the failure of the research/extension community to address the needs of the commercial grower.

1. The "Conjunto Technológico" recommends the use of the Charleston Gray variety of watermelon and indicates that commercial yields should be in the range of 12 tons/acre. However, commercial yields typically fall in the range of 2-4 tons/acre, and the highest-yielding commercial field the authors know of yielded 8 tons/acre using gravity irrigation.

2. The "Conjunto Technológico" recommends use of the Walter variety of tomato on Puerto Rico's semi-arid south coast region. However, commercial experience with the Walter variety has been disastrous; it tends to produce small (low value) fruit. Both local and Israeli farmers encountered this problem during the winters of 1978-79 and 1979-80, and to the authors' knowledge this variety has not been planted commercially in Puerto Rico since then.

3. The "Conjunto Technológico" describes procedures for gravity irrigation of honeydew melons. Although honeydew melons is currently one of the principal vegetable crops grown in the semi-ared zone of Puerto Rico (on the Israeli farms), the authors know of no field which has ever been grown using gravity irrigation. Furthermore, due to a multitude of problems related to disease control and fruit blemish, the production of honeydew melons in Puerto Rico using gravity irrigation is definitely not recommended.

4. The publication is out-of-date; the most recent version is dated March 1979.

5. The "Conjunto Technológico" describes production techniques for 12 different vegetable crops in only 68 pages. This "cookbook" approach which might be adequate if there were indeed a well-developed and well-defined commercial technology. However, this is not the case.

In summary, the production technology presented by the Experiment Station in its "Conjunto Technológico" does not constitute commercially feasible practice.

One of the key problems with the "Conjunto Technológico" is that the Agricultural Experiment Station has made little or no effort to incorporate the results of commercial experience in its technological package. The problem with watermelon previously cited is one glaring example. Watermelon was one of the principal crops planted in the

Vegetable Program during 1977-79 and yields were disastrously low (the highest-yielding field on all farms produced about 8 tons/acre, most fields produced in the 3-4 ton/acre range). Yet, the recommendations for commercial production contained in the current (1979) version of the "Conjunto Technológico" did not reflect the results of actual commercial experience, even though Experiment Station personnel were visiting the very fields which were experiencing these problems during 1977 and 1978 (authors' personal experience).

The wealth of commercial experience gained on Israeli farms has, to date, not been shared with other farmers even though these operations were financed using loans and loan guarantees provided by the Commonwealth government. However, even if this information were to be made available it still offers a poor substitute for hands-on field experience.

Traditional research-extension methods and present levels of funding are inadequate to address the magnitude of the problem which exists in the U.S. Caribbean. Only a few crops are presently commercially successful in the semi-arid Caribbean, and fundamental commercialization research must focus on potential crops, rather than on merely refining development techniques for existing crops. For instance, Tahal (1984, pV-50) recommended that research expenditures be nearly doubled. A vigorous and well funded research-extension program is needed which simultaneously involves researchers, extensionists and farmers in the development of commercial agronomic techniques on semi-commercial scale fields (similar conclusions were reached by Tahal, 1984, pV-50).

In developing the recommendations in this report it is necessary to take issue with the generally optimistic results which are reported by researchers, as opposed to the frequently pessimistic results which are achieved by farmers under commercial conditions. For example, recently published crop budgets (Table 7) showed vegetable production to be highly profitable. Similarly optimistic earnings figures are contained in Puerto Rico's Agricultural Plan (Vicente-Chandler et al, 1978) and are also reported by Tahal (1984).

TABLE 7: NET INCOME REPORTED FOR VARIOUS CROPS IN THE SEMI-ARID ZONE OF PUERTO RICO DURING THE 1982-83 CROP YEAR (Llorens et al, 1984).

Crop	Irrigation system	Net income or (loss) per acre
Pepper	furrow	$1,945
Pepper	furrow	2,571
Cucumber	furrow	1,382
	sprinkler & furrow	1,021
Eggplant	sprinkler & furrow	930
Calabaza	furrow	802
Calabaza	drip	746
Tomatoes	drip	3,425
Honeydew	drip	1,185
Watermelon	drip	(290)

Although the levels of income suggested in Table 7 can indeed be realized, they are not realized on a consistent basis on commercial farms. A combination of production and marketing problems, plus vagaries of weather, create an economic panorama much different from the rosy picture of "profits everywhere" suggested by researchers.

For example, despite the high level of income reported for cucumbers (net income of $1,382 per acre on a 45 day crop) Llorens et al noted that the cucumber harvest declined from 680 acres in 1978-79 to only 79 acres in 1982-83. Contrary to the high earnings reported by researchers, farmers have found the production and marketing of cucumbers to be unprofitable. That acreage of vegetables harvested is not increasing, and may even have declined in the past two years, underscores the gross disparaties between published research data and commercial experience.

The urgent need to strengthen research, and extablish a two-way flow of information between the research-extension community and commercial farmers, is further underscored by the results in Table 8, which compares yields obtained for various crops in Puerto Rico by researchers and commercial farmers. Note that commercial farmers have achieved much higher yields than researchers on many crops, and that no research has been conducted on honeydew melons, one of the principal crops in the semi-arid zone in Puerto Rico. This indicates that research knowledge lags significantly behind commercial practice, clearly demonstrating the need to strengthen research and related infrastructure. The closing of the gap between researchers and commercial farms must be the principal focus of the research community if research is to be effective.

TABLE 3: YIELDS OF VARIOUS CROPS ATTAINED IN THE SEMI-ARID ZONE OF PUERTO RICO USING DRIP AND CONVENTIONAL IRRIGATION.

Crop	Drip Irrigation				Conventional Irrigation	
	Agricultural Experiment Station 1/		Private Growers 2/		Private Growers 2/	
	(Box/Ac)	(Tons/Ac)	(Box/Ac)	(Tons/Ac)	(Box/Ac)	(Tons/Ac)
VEGETABLE CROPS:						
Tomatoes	669	10.0	1000-2000	15-18.7	600	7.5
Peppers (cubanelle)	528	10.5	800-1000	20-30	400	8.0
Eggplant	668	13.3	1000	20	400	8.0
Cucumbers	921	18.4	500-1000	12-25	250	6.0
Squash	--	20	--	10	--	6
Watermelon	--	12.7	--	2-3	--	3
Honeydew melon	not investigated		800-1500	10-18	not attempted	
Cabbage	--	15.6	--	10	--	5
Onion	--	10.4	--	10	--	5
Sweet potato	not investigated		--	10	--	10
TREE CROPS:						
Mango (after 6 yrs)	--	18	--	4-10	--	--
Plantain 3/	35,000 fruit	21	40,000 fruit	24	30,000	18
Bananas	1200	24	1000-1300	20-26	700	14
Papaya	not investigated		--	40	--	25
Avocado	--	3.5-5.0	--	4-5	--	3-4

1/ Goyal and Rivera, 1985

2/ Yield data from local growers on the south coast of Puerto Rico as compiled by the authors over the period 1977-1985.

3/ Yield computed based on 0.6 lb/fruit avg. weight, since this crop is normally sold on a count basis rather than by weight.

STRATEGIES FOR IMPROVING
SEMI-ARID AGRICULTURE PRODUCTION TECHNOLOGY

Although water supply ultimately limits agricultural production in the semi-arid zone, the principal constraint today is not the availability of irrigation supplies. Many farmers have gone bankrupt despite adequate water supplies; the principal problem is uneconomically low yields for the prevailing market conditions.

Commercial agriculture has traditionally focused on plantation sugarcane and the use of low-wage labor. This tradition has not provided the orientation and expertise required to successfully manage sustained high-yield commercial farms in today's competitive, high-wage environment. Furthermore, past agricultural tradition has not endowed the U.S. Caribbean with many forms of essential agricultural infrastructure that are taken for granted on the mainland. This stands in stark contrast to mainland farmers who benefit from a tradition of family farming and are aided by the decades-long accumulation of practical local experience plus production, marketing, financial and research background.

Despite dramatic differences in the agricultural conditions in Puerto Rico and the Virgin Islands, agricultural development in both areas has suffered from the same problem: development projects have been implemented in a piecemeal rather than an integrated fashion. Critical components of support infrastructure have been omitted in major agricultural development projects, resulting in project failure.

Puerto Rico

In contrast to the limitations in the Virgin Islands to be discussed subsequently, agricultural development in Puerto Rico would seem relatively easy. However, there are several important constraints, including the lack of proper production technology and much lower market prices for agricultural products. However, inputs such as land, water, and labor are readily available. Despite these advantages vis-a-vis conditions in the Virgin Islands, Puerto Rico has encountered serious difficulties in re-developing the agricultural sector in the semi-arid zone following the demise of the sugarcane industry.

In 1977 the Commonwealth government undertook an ambitious Vegetable Program to initiate commercial vegetable production on Puerto Rico's south coast, promoting the establishment of 14 private farms on approximately 5,000 acres. The Vegetable Program was established on the fundamental premise that the technological production package developed by the Puerto Rico Agricultural Experiment Station, when applied to commercial operations, would produce profitable levels of yield. However, experience showed that this was not true. Farmers were faced with a number of extremely serious production and marketing problems which the sponsoring agencies were either unable or unwilling to solve. As a result all but one of the original farms that produced vegetables on a significant scale have since gone through bankruptcy proceedings.

Rather than work with the original farmers to improve production technology, the Commonwealth Department of Agriculture subsequently invited two Israeli groups to participate in the Vegetable Program which led to the development of two "showcase" farms on a total of about 4,000 acres using over $40 million in local government loans and loan guarantees. The two Israeli-managed farms:

* Installed approximately 4,000 acres of drip irrigation,

- Undertook extensive research efforts using both small plots and commercial size trials, experimenting with many alternative crops and varieties,
- Constructed and operated packing sheds, marketing large volumes of produce to the U.S. mainland and Europe,
- Consumed approximately half of all commonwealth government agricultural credit available in all of Puerto Rico, and
- Lost money year after year.

At the same time financing for the installation of drip irrigation and related infrastructure was denied to local farmers.

On the positive side these two Israeli farms did eventually achieved high yields on a variety of crops. In contrast to the situation in most areas, where experimental yields greatly exceed the yield from commercial fields, the yields on some of the Israeli farms greatly exceed the highest yields obtained by the local experiment station (the drip-irrigated vegetable crops listed in Table 8 were grown on Israeli-managed farms). These high yields have persuaded many local farmers and government officials that an integrated package of drip irrigation technology is the most promising avenue for achieving profitable levels of production on high-value crops.

However, the high yields have been obtained only as a result of an extremely costly start-up and experimental period. The Puerto Rico Secretary of Agriculture stated that, *"The two Israeli firms which produce vegetables in Santa Isabel owe $44 million to the state, against which not a single payment has been made"* (El Mundo 4/16/85 p4, author's translation). Elsewhere it has been reported that one of the two Israeli firms *"has lost $20 million since it began and is not even* *close to breaking even, despite last year's profit."* (San Juan Star, 4/29/85 p1). This uncertain financial condition of the Israeli farms constitutes one more factor at variance with the impression of high profits suggested in the crop budgets published by researchers.

Even though the great expenditures on the two Israeli farms were justified as the cost of obtaining new agricultural technology, no provision was made for the transfer of this technology to local farmers. Descriptions of the technological packages used by the Israeli farmers are not available for local farmers, and credit has not been available for the installation of drip irrigation equipment on non-Israeli farms. As a result, these costly "agricultural development" expenditures have had little, if any, positive impact on local farmers. In fact, many local farmers feel that the presence of the Israeli farms has been detrimental to date, since they have invaded local markets which otherwise could have been served by local farmers.

Have the Israeli farms been successful? On the positive side, they have developed and demonstrated high yield agriculture. However, on the negative side, tthere has been no transfer of the technology used to achieve high yields. Thus, while it has been demonstrated that high productivity can indeed be achieved, the technological package utilized to produce these remarkable results remains hidden to all but its originators.

U.S. Virgin Islands

The constraints to agricultural development are much more severe on the Virgin Islands than in Puerto Rico. The difficulty of agricultural development in the Virgin Islands is suggested by Gerber (1979):

> *"The pessimist will claim that we have a water problem, a labor problem, a marketing problem, and there is little good land available for production. The pessimist is correct."*

Padda (1981) enumerated the following constraints to agricultural development in the Virgin Islands:

- lack of available land
- lack of adequate credit facilities
- lack of trained personnel
- labor shortage
- lack of proper technology
- lack of adequate water supplies
- insufficient marketing facilities

The synthesis of this problem by the authors of this paper revealed the following additional fundamental constraints:

- Low government priority. Agricultural development is not a top government priority, and the available resources do not effectively reach farmers. For example, the 1983 budget of the U.S. Virgin Islands Dept. of Agriculture was $2.16 million, but less than 10% of this amount was actually delivered as services to the farmer. The remaining 90% was consumed by salaries and administrative costs (Source: Budget, U.S. Virgin Islands Dept. of Agriculture). The Department of Agriculture's budget was over four-times the value of crop production as reported in the Census of Agriculture (recall Table 1).

- Lack of integrated development programs. Effective mechanisms do not exist to transfer the available technology to farmers and assist them establish commercially viable operations. To be successful in the U.S. Virgin Islands a development program should provide an integrated package of inputs including land availability, credit, extension, water and related infrastructure, and possibly marketing assistance. However, critical components are typically lacking from agricultural development efforts.

  For example, in a semi-arid environment it should be obvious that water is required in order to achieve economic levels of production. Nonetheless, this basic precept has been ignored in the Harvey Lands Agricultural Park which was established on St. Croix by the government of the Virgin Islands. Water supply was just one of several important inputs which was not available. Predictably, this costly project has not been successful.

- Lack of program continuity. Agricultural research and development projects require continuity and long-term (10-15 years) committment. The high turnover of extension and research staff at the College of the Virgin Islands is a serious impediment to program continuity.

* Labor supply. Although mentioned previously, it merits repeating that the lack of reliable agricultural workers, even at wages of $5 per hour, is a very serious impediment to agricultural development in the U.S. Virgin Islands.

Commercial production cannot be successfully undertaken without addressing all of these problems simultaneously, and until an integrated development package can be put in place little change can be expected from the present situation.

Summary

Agricultural development in the semi-arid zone in both Puerto Rico and the Virgin Islands has been severely constrained by the failure of agricultural programs to support the development of essential elements of infrastructure: an integrated development approach has not been pursued. Failure has not occurred for lack of economic resources. Rather, the available resources have not been used efficiently.

The many factors constraining agricultural development are best summarized as "lack of commercial-oriented production expertise" on the part of farmers, extensionsits and researchers. Without the requisite expertise, gained under local conditions, it is not possible to achieve profitable yields. Although high yield technology has now been demonstrated on a commercial scale on government-financed Israeli farms in Puerto Rico, and at the U.S. Virgin Islands Agricultural Experiment Station, there is no mechanism for local farmers to benefit from this technology and learn to adapt these techniques.

Experience has shown that farmers (including experienced local and Israeli agronomists) invariably lose money during startup as they attempt to develop high-yield technology in the absence of effective inputs from research and extension. When high-value crops are involved these losses may easily exceed $1,000 per acre per crop. Because local farmers cannot sustain these losses associated with the development of technology, innovative farms have suffered heavy losses and a number have filed for bankruptcy.

The recommendations which follow stem directly from the critical need to develop and demonstrate sustained high-yield production technology in a public rather than a private environment through cooperative extension projects, thereby making it available to local farmers.

SUMMARY: CONSTRAINTS AND OPPORTUNITIES

Principal Constraints

The most fundamental constraint impeding agricultural development is the lack of understanding and experience in the application of sophisticated high-yield agricultural technology to local conditions. Not only the farmers lack experience; most extension and research personnel also lack experience with this technology and are therefore not competent to guide farmers. That commercial yields on Israeli farms are nearly double the yield obtained by local researchers is a good indicator of the state of current research knowledge. Lacking state-of-the-art crop production technology, economical levels of production are not obtained, despite the availability of other inputs such as water, labor, irrigation equipment, etc.

In those instances where high-yield techniques have been demonstrated by researchers, effective mechanisms do not exist for transferring this technology to farmers. Tahal (1984, pV-52) also cited inadequate research, the lack of technology transfer and inadequate support services (registration of new chemicals, foliar analysis, etc.) as important constraints. As previously cited, the technology developed and demonstrated by Israeli farmers is also not available to local farmers.

The volume of water supplies, while limiting the potential growth of the agricultural sector, presently does not constrain production in Puerto Rico. In the Virgin Islands water supply is much more constraining than in Puerto Rico and the provision of water supply infrastructure must be an important focus of agricultural development activities.

An additional constraint important in the Virgin Islands but not in Puerto Rico is the lack of agricultural labor. Farmers interviewed in the Virgin Islands complained that labor was high cost ($5.00/hour) and unreliable. For the time being this problem can probably best be avoided by promoting small farms which minimize labor inputs to that which the farmer can supply from his family. In Puerto Rico the labor supply is adequate and of good quality.

Principal Opportunities

The U.S. Caribbean enjoys a favorable climate, adequate soil and water resources, excellent transportation and communication infrastructure, access to markets, and (in Puerto Rico) a technically sophisticated and readily available labor force. What is lacking is the hands-on technological experience and local know-how required to translate these resources into economically viable, high-yield, agricultural enterprises. The financial and technical resources of private farmers are inadequate to undertake the repeated production trials required to develop high-yield technology tailored to local conditions.

By undertaking a vigorous and innovative research-extension program in cooperation with progressive local farmers, it may be possible to develop and demonstrate agronomic packages which can generate profitable yields in crops which have yet to be successfully exploited commercially on non-Israeli farms.

Appropriate Congressional Objectives

The federal government has historically assumed a leading role in the advancement of agricultural technology, and it should also assume this key role in the U.S. Caribbean. Furthermore, an innovative and vigorous role may be assumed utilizing existing administrative structures if budgetary resources are provided by Congressional appropriation.

Federal Programs

The two most important federal programs which can support the development of sustainable agriculture are the cooperative research and extension programs administered through the Agricultural Research Service and the Extension Service. Both programs have provisions for cooperative projects with local farmers, which is a highly appropriate avenue for supporting the development and dissemination of agricultural technology in the semi-arid zone.

Recommended Actions to Mitigate Production Constraints

Federal government. Provide $1-2 million per year over a five year period for funding research-extension cooperative projects with progressive farmers in the semi-arid zone, plus the cost of USDA specialists and support activities. Cooperative projects may be funded through existing USDA administrative channels in the Agricultural Extension Service as well as Agricultural Research Service (Tropical Agricultural Research Station at Mayaguez).

Cooperative projects should be undertaken on commercial or semi-commercial scale fields on private farms, and should focus on the development and application of complete crop management packages (in Puerto Rico, minimum field size should be 1 acre; in St. Croix it would be much smaller). Cooperating farmers should have demonstrated initiative and ability in the field, be good communicators, and maintain accurate records of income and expense. Cooperative plantings should be repeated for several years to demonstrate replicability of results and permit refinement in technique, which has been a critical shortcoming in the research to date. The cost of all inputs and some labor should be provided under the cooperative agreement as an incentive to the farmer to undertake production of these high risk crops, which may presently lack adequate marketing facilities.

Research and extension personnel should work together, and along with the farmer, to facilitate the three-way flow of information. Local research-extension personnel should be augmented with USDA specialists on two-year leave, plus additional specialists on short term assignments. All agronomic practices, economic cost and income, water use and other information should be carefully documented, published, and disseminated to farmers at seminars, workshops and field days. Nonetheless, it is expected that the most important means of disseminating this information will be individual contacts between the cooperating farmer and his neighbors.

Cooperative projects on farms should be complemented with experimentation on small plots to better answer specific questions relating to fertilizer response, dosage rates for chemicals, variety selection etc. Cooperative projects should include a range of crops which show economic potential, including both high and low value crops.

This program should not focus on the development of exotic new technologies, but rather should obtimize the combination and utilization of existing technologies. For example, in Puerto Rico the project should not focus on the use of a single type of irrigation system. Rather, drip irrigation, gravity irrigation, or sprinkler irrigation should be used in accordance with the terrain and crop requirements and consistent with maximizing economic return.

The final goal of this project will be to develop and demonstrate economically viable crop production technologies and to disseminate this information among local farmers, researchers and extensionists, thereby creating the body of expertise required to successfully undertake commercial production.

Local Government. The above recommended program must be closely coordinated through the local government to be successful. Local government will also need to provide sources of credit and assistance in development of infrastructure. In Puerto Rico most local administrative structures required to support these programs have evolved and are already in-place, and essential irrigation infrastructure is planned for the near future. However, in St. Croix the local government will need to focus on developing irrigation supplies (eg. Harvey Lands area) and other essential types of infrastructure including a well-designed package of supervised credit.

Expected Consequences of Recommended Actions

It is expected that consistently high yields can be demonstrated for a variety of crops which have not yet been successfully exploited commercially. Favorable production experience will support and promote those improvements in post-harvest and marketing techniques that are required to translate high yields into commercially viable enterprises. The examples set by the cooperating farmers, plus research information and experience gained during the project, will serve as a catalyst for the development of successful enterprises and a self-sustaining pattern of agricultural development.

Tahal (1985, pIV-67) calculated the following range of potential economic and employment impacts for various irrigated farm configurations on Puerto Rico's south coast:

Gross income/acre	\$1,980 - \$5,390
Employees/100 acres	7.2 - 17.6

Using \$3,500 per acre and 12 employees/100 acres as average numbers, over an irrigated area of 40,000 acres this translates into \$140 million per year in income and 4,800 direct employees. These impacts are of no small consequence in Puerto Rico where islandwide the unemployment rate exceeds 23%.

The recommended actions should permit previously irrigated lands to be brought back into production. If operation rules for the irrigation districts are changed using the strategies recommended in this report to avoid saline intrusion, no adverse environmental impacts are forseen.

REFERENCES

Adolphson, D. G., M.A. Seijo and T, M, Robison. "Water Resources of the Maunabo Valley, Puerto Rico. Water Res. Investigation 115-76. USGS, San Juan. 1977.

Barnaby, J. Watten and Robert L. Busch. "Tropical production of tilapia and tomatoes in a small-scale recirculating water system." Aquaculture, 41:271-283. 1984.

Calvesbert, Robert J. "Climate of Puerto Rico and U.S. Virgin Islands." U.S. Dept. of Commerce, Climatography of the United States No. 60-52. U.S. Govt. Printing Office, Washington, D.C.

El Mundo, daily newspaper, San Juan.

Freeze, R. Allan and John A. Cherry. Groundwater. Prentice-Hall. Englewood Cliffs, New Jersey. 1979.

Gerber, John. "The potential for commercial vegetable production in the Virgin Islands." in 9th Annual Agriculture and Food Fair of the Virgin Islands. U.S. Virgin Islands Dept. of Agriculture. 1979

Giusti, Ennio V. "Water resources of the Juana Díaz area, Puerto Rico: A preliminary appraisal, 1966." Water Res. Bull. 8, USGS-WRD, San Juan. 1968.

Giusti, Ennio V. "Water resources of the Coamo area, Puerto Rico." Water Res. Bull. 9 USGS-WRD, San Juan. 1971.

Goyal, M.R. "Annual Report No.3, 1983-84, Trickle Irrigation in Humid Regions, Puerto Rico". Ag. Exp. Station, Univ. P.R. Rio Piedras. 1984.

Goyal, M.R. and L.E. Rivera. "Trickle Irrigation Scheduling in Vegetables". Paper presented at Third International Drip/Trickle Irrigation Congress (in press). 1985.

Heisel, J.E. and J.R. Gonzalez. "Water Budget and Hydraulic Aspects of Artificial Recharge: Puerto Rico." USGS Water Resources Invest. 78-58. San Juan. 1979.

Jordan, Donald G. "A Survey of the Water Resources of St. Croix, Virgin Islands." Open-File Report, U.S. Geological Survey, Water Resources Div., San Juan. 1975.

Lizardi, Gonzalez and Maldonado Consulting Engineers "201 Facilities Plan: Lajas-Boquerón Region". Report to P.R. Aqueduct & Sewer Authority, San Juan. 1975.

Llorens, Antonio A., Eduardo González-Villafañe and Daniel Vargas. "Gastos y Ingresos en la Producción de Hortalizas en la Costa Sur de Puerto Rico". Bull. 274, Ag. Exp. Station, Río Piedras. 1984.

McClymonds, Neal E. and José Raul Díaz. "Water resources of the Jobos area, Puerto Rico." Water Res. Bull. 13. USGS-WRD, San Juan. 1972.

Morris, Gregory L. "Regional Development and Water Resource Management: Implications of a Changing Agricultural Sector on Puerto Rico's South Coast." Ph.D. dissertation, Univ. of Florida, Gainesville. 1979.

Morris, Gregory L. "The Effect of Irrigation Modernization on Groundwater Balance: South Coast of Puerto Rico." Proceedings International Symposium on Tropical Hydrology. May 5-8, 1985. Avail. from Am. Water Res. Assn., Bethesda, Md.

Office of Technology Assessment. Water-Related Technologies for Sustainable Agriculture in the U.S. Arid/Semiarid Lands. OTA-F-212, U.S. Congress, Washington, D.C., 1983.

Padda, D.S. "Agricultural potentials and constraints in the Virgin Islands. 11th Annual 1981 Food Fair of the Virgin Islands jointly sponsored by Virgin Islands Dept. of Agriculture and College of Virgin Islands Cooperative Extension Service. 1981.

Rakocy, James E. "A recirculating system for tilapia culture and vegetable hydroponics in the Caribbean." Paper presented at Auburn Univ. Fisheries and Aquaculture Symposium, Sept. 20-22, 1984. Mimeo avail. from College of the Virgin islands, Ag. Experiment Station. St. Croix.

Rakocy, James E.; John A. Hargreaves; and Ayyappan Nair. "A rainwater catchment system for agricultural water supply". Proc. of 2nd Intl. Conf. on Rain Water Cistern Systems, Caribbean Research Inst., College of the Virgin Islands, St. Thomas. 1984.

San Juan Star, daily newspaper, San Juan.

Tahal Consulting Engineers, Ltd. "Programa Estrategico Para el Desarrollo Itegrado del Sector Agropecuario en el Proximo Decenio". Report to P.R. Dept. of Agriculture, San Juan. 1984.

U.S. Bureau of the Census. "1982 Census of Agriculture". U.S. Govt. Printing Office.

U.S. Department of Agriculture. "Soil Survey of Ponce Area of Southern Puerto Rico". Soil Conservation Service, San Juan. 1979.

University of Puerto Rico. "Conjunto Technológico para la Producción de Hortalizas". Pub. 102, 2nd Edition. Estación Experimental Agrícola. Río Piedras. March 1979.

Vásquez, Roberto and J. Ortiz Vélez. "Drainage and Ground-Water Research in Lajas Valley, Puerto Rico". Bull.206. Ag. Exp. Station, Río Piedras. 1967.

Vicente-Chandler, José et.al. "Conceptos, Plan y Programa Para Una Agricultura Moderna en Puerto Rico." P.R. Dept. of Agriculture, San Juan. 1978.

V.I. Experiment Station "Report of the Virgin Islands Experiment Station". St. Croix, U.S. Virgin Islands. 1932.

INDIVIDUALS CITED

Borrero, Miguel
Assistant Director
Puerto Rico Sugar Corporation
Puerto Rico Department of Agriculture

Buzdugan, Stephen C.
Agricultural Engineer/Irrigation specialist
Agricultural Experiment Station
College of the Virgin Islands, St. Croix

College of the Virgin Islands. "1981-1982 Report, Agricultural Experiment Station, Cooperative Extension Service." St. Thomas

Green, Kenneth
Director
Agricultural Experiment Station
College of the Virgin Islands, St. Croix

Matusazk, John
Cooperative Extension Agent
Agricultural Experiment Station
College of the Virgin Islands, St. Croix

Meyer, Lewis
Asst. to the Director
Puerto Rico Vegetable Program
P.R. Land Authority, Santa isabel, PR.

Peterson, Arthur C.
Vegetable Crop Specialist
Agricultural Experiment Station
College of the Virgin Islands, St. Croix

Rakocy, James E.
Fish Culture Specialist
Agricultural Experiment Station
College of the Virgin Islands, St. Croix

Sánchez, Joselo
Executive Director
Puerto Rico Land Authority
P.R. Dept. of Agriculture

Background Paper No. 2

ASSESSMENT OF AGRICULTURAL PRODUCTION TECHNOLOGIES FOR U.S. CARIBBEAN ISLANDS

by

Jose Vicente-Chandler

1986

Prepared for

U.S. Congress, Office of Technology Assessment,
Integrated Renewable Resource Management for U.S. Insular Areas,
Washington D.C.: U.S. Government Printing Office, 1987.

ASSESSMENT OF AGRICULTURAL PRODUCTION TECHNOLOGIES FOR U.S. CARIBBEAN ISLANDS

CONTENTS

PUERTO RICO

I. INTRODUCTION

II. WATER RESOURCES

- A. Humid Mountain Region
- B. Humid Coastal Areas
- C. Semiarid South Coast

III. SOIL RESOURCES

- A. Need for Concentrating Commodities in Different Areas
- B. Commodities for Mechanizable Lands
- C. Commodities for Partially Mechanizable Lands
- D. Commodities for Other Lands

IV. AGRICULTURAL COMMODITIES

- A. Sugarcane
- B. Rice
- C. Vegetables
- D. Pineapples
- E. Pigeon peas
- F. Grains
- G. Milk
- H. Hay
- I. Beef

J. Coffee
K. Plantains
L. Bananas
M. Mangos
N. Citrus
O. Root Crops
P. Poultry
Q. Pigs
R. Ornamentals
S. Aquaculture
T. Commercial Forests
U. New Crops - Cocoa, Oil Palm

V. CONSTRAINTS TO AGRICULTURAL PRODUCTION
A. Land Improvement
B. Land Tenure
C. Availability of Land
D. Human Resources
E. Technology and Technology Transfer
F. Credit
G. Marketing
H. Materials and Services
I. Government Action and Incentives

U.S. VIRGIN ISLANDS

I. INTRODUCTION
II. WATER RESOURCES

III. SOIL RESOURCES

IV. AGRICULTURAL COMMODITIES

  - A. Milk
  - B. Beef
  - C. Pigs, Poultry and Goats
  - D. Fruits and Vegetables
  - E. Woodland

V. CONSTRAINTS TO AGRICULTURAL PRODUCTION

VI. BIBLIOGRAPHY

ABSTRACT

The U.S. Caribbean Islands are located about 1,000 miles East Southeast of Florida with an area of 3,571 square miles and have a population of about 3.3 million. There are about 280,000 acres of prime agricultural lands and about 600,000 suited to soil conserving, non mechanizable crops.

Rainfall ranges from 25-180 inches and climate is tropical oceanic with mean annual temperatures from 21-26°C.

The Islands have a good infrastructure of roads, telephone, water and electricity and islanders are in close contact with the Mainland, where over 2 million reside. Per capita annual income is $4,000, half that of the poorest State but one of the highest in Latin America. Federal transfer payments account from about 25% of income.

The Islands' economy was largely agricultural but industries, tourism and construction have boomed during the last half century whereas agriculture has been neglected. Altho crop production has decreased over the past 30 years, production and consumption of milk, eggs, poultry and pigs fed on imported concentrates has increased rapidly. About $1.25 billion of food are imported yearly.

Agriculture must be completely modernized if it is to compete with imports from the highly efficient Mainland agriculture or from Latin America, where land and labor are cheap. Although Puerto Rico could be self-sufficient in food production with only limited changes in consumption, this goal is not realistic at present. However, the Island has excellent soil and water resources, year-round growing weather, a good infrastructure, adequate capital, well trained young people, an excellent market and the necessary technology to create a modern agriculture.

Monthly rainfall exceeds potential evapotranspiration in the humid mountains of Puerto Rico where about 600,000 acres are suited to such crops as pastures, coffee, bananas, plantains, citrus and cocoa which are soil conserving, do not require mechanization and can tolerate periodic droughts. About 300,000 additional acres are suited to commercial forests and could supply the local market. There are 270,000 acres of mechanizable lands with sufficient water from rainfall or irrigation to grow a variety of crops such as rice, sugarcane, vegetables, fruits and grain. In the Virgin Islands only 12,000 acres are mechanizable, rainfall is less than in Puerto Rico and there is sufficient water to irrigate only 1,000 acres for fruit and vegetable production with the remainder, together with additional, partially mechanizable lands used for milk and beef production for the local market. Crops should be located in the areas best suited to their efficient production with maximum utilization of land and water resources in order to maximize agricultural production.

In Puerto Rico, it is suggested that sugar production be limited to 40,000 acres to supply the local market and rice on 40,000 acres could supply 80% of the local market. The local market for fresh vegetables could be supplied during the winter and exports increased during this season. Pineapples for export could be planted on about 12,000 acres. Pigeon peas on 7,000 acres could supply the local market, and some grain could be produced on about 40,000 acres. Milk production, based on tropical grass pastures, should be limited to the local fresh milk market and beef production should increase slowly. Pigs and poultry production should be increased only to the point of supplying the local market willing to pay higher prices fresh products. All coffee, plantains and bananas for the local market could be produced on about 50,000 acres. There is potential for creating a banana export industry and the mango industry should continue to be rapidly developed for export. Citrus and other fruits should be limited to the local market as should production of root crops and commercial forest production. Ornamentals should be increased for the export market, aquaculture and mariculture deserve special attention. The production of cocoa and palm oil requires further research.

The Virgin Islands can be self-sufficient in fresh milk and production of other animal products increased. If all resources are used and marketing problems solved, they could also produce most of the fresh vegetables and fruits. Construction of ponds for irrigation should receive highest priority.

About 90,000 acres require efficient irrigation and drainage systems and an additional 60,000 acres require drainage. Farms of sufficient size to provide the owner with an attractive income should be favored and efforts made to increase availability of agricultural lands. Human resources must be developed and new methods used for technological transfer. Agricultural credit must be sharply increased and marketing systems improved.

Agricultural production requires considerable support from federal and local governments as described in this report.

POSSIBLE ACTION BY FEDERAL GOVERNMENT

1. Assign a specific proportion of the Federal Food Stamp Funds (PAN) and/or, any increases in these funds to increase employment and productivity in agriculture. Increased income to laborers could reduce payments for food stamps and unemployment compensation and reduce migration to the Mainland. Unemployment now exceeds 20% officially but in reality is much higher and lies at the root of many of the Island's social problems. One such program could be planting of commercial forests on private lands not suited to agriculture. About 300,000 acres of such lands, if planted to Honduras pine, could make the Island self-sufficient in wood products. The planting of tree crops which are soil conserving, such as coffee, cacao, mangos, and even bananas which are replanted only at 10-15 year intervals, could also be included, as well as planting pastures for conservation and meat and milk production in the mountain region.
2. Food stamps funds could be used to reimburse the Puerto Rico Government for the supplemental salary payments now made to agricultural workers at a cost of about $25 million yearly. This action should be conditioned to use of the reimbursed funds to increase food production on the Island.
3. Assign a proportion of food stamp funds to permanent improvements for increased food production such as the construction of dams and water distribution systems, leveling agricultural lands and establishing efficient irrigation and drainage systems.
4. There is great need for a long-term plan and program for increasing food production in Puerto Rico and the Virgin Islands. Such a plan

PUBLISHERS NOTE:

THE FOLLOWING PAGE WAS OMITTED
IN THIS PRINT. # 70 .

from various sources including water from present inefficient irrigation systems and use of treated waste water for irrigation as well as the possibilities of transferring water from humid areas.

8. Increase funds for Research and Extension and target them to specific crops and problems, with applicability to large areas in the Caribbean Basin. The Puerto Rico Experiment Station and Extension Service have received relatively small increases in funding compared to the rate of inflation over the past decade. Technology developed in Puerto Rico is transferable to other U.S. territories and to countries in the Caribbean Basin.

9. Increase support for an expanded program of winter nurseries in Puerto Rico. The productivity of breeding programs in the U.S. Mainland could be doubled by producing an additional generation during the winter in Puerto Rico. Limited winter nurseries for rice, sorghum and corn are operating in Puerto Rico,with considerable funding from U.S. industries, and could be greatly expanded to include crops such as wheat, barley, oats, soybeans and dry beans.

   Funds could be assigned to increase plant introductions and evaluations in the Virgin Islands with crops of interest to the United States and which cannot be introduced directly due to quarantine restrictions.

   The current program at TARS for maintaining germplasm of tropical crops which cannot be propagated from seed, or whose seed cannot be stored for prolonged periods, should be expanded to serve the Caribbean Basin and much of the Tropics. Such crops as bananas, plantains, cacao, mangos, avocados, oil palm, and tropical root crops could be included.

10. Change the current systems for registering pesticides so that those approved for the Southern United States are also approved for the

same crops in Puerto Rico. At present, restricted pesticides must go through the process of local registration which is costly to manufacturers compared to the potential market on the Island.

11. Raise the limit for exemption of payment of minimum federal wages for non mechanizable agricultural operations in the mountain region from 4,000 to 6,000 man-hours per trimester. Even large mechanized operations on the Mainland require less than 4,000 man-hours per semester and are therefore exempt from paying federal minimum wages. Also much of the labor for vegetable and fruit crops is piece-work performed by migrant labor and is not considered in determining applicability of federal minimum wages. Migrant labor is not available in Puerto Rico and all wages except for picking coffee are on an hourly basis.

12. Develop a program for insuring commercial forests against damage by hurricanes. If an actuarial study indicates that premiums will be too costly to farmers, consideration should be given to partially subsidize these payments.

13. Develop and approve a mechanism for automatically implementing federal anti dumping legislation whenever Mainland produce is sold in Puerto Rico or the Virgin Islands at below production costs. This legislation is at present inoperative due to the time required, and technical difficulties involved, in implementation.

14. Exempt 936 Corporations funds from federal taxes while they are invested in agricultural loans at moderate interest rates or in long-term loans to the Puerto Rico Government for making permanent improvements such as water storage and distribution facilities, land leveling and construction of efficient drainage and irrigation systems.

ASSESSMENT OF AGRICULTURAL PRODUCTION TECHNOLOGIES FOR U.S. CARIBBEAN ISLANDS - PUERTO RICO

INTRODUCTION

Puerto Rico is located about 1,000 miles East-Southeast of Florida, at about North latitude 18 and West latitude 66. It is approximately 3,435 miles square with narrow coastal plains rising gradually towards the interior mountain ranges, which account for most of the Island's surface and have peaks as high as 4,400 feet. Rainfall ranges from 30 to 180 inches yearly (Figure 1). The climate is tropical-oceanic with mean annual temperatures ranging from 21 to 26°C, depending on elevation. Daily maximums rarely exceed 32°C and minimums are rarely below 18°C.

Population is 3.3 million or about 930 persons per square mile or 1.5 per acre, one of the highest densities in the World. There are 12 persons for every acre of mechanizable lands and about 3 for every acre of land that can be used for agriculture, including commercial forests (Vicente-Chandler 1978).

The Island has an excellent network of roads, telephone service is available islandwide and over 90 percent of the homes have electricity and drinking water. There are over 1 million vehicles, one per three persons, and almost all homes have a radio and TV set.

Puerto Rico has very close contacts with the United States Mainland. Over 2 million Puerto Ricans live there and most Island residents travel frequently to the Mainland. Indeed, with the exception of the West Central Mountains, much of Puerto Rico can be visualized as an extended sub-urban area of the large Eastern cities. This close relationship has strongly affected Puerto Rican culture, which combines Latin and Anglo-Saxon characteristics including the high material aspirations of the latter.

Puerto Rico's GNP is approximately $13 billion, equivalent to $4,000 per capita, about half that of the poorest State of the Union but one of the highest in Latin America. During the last decade, federal transfer payments have grown to about $4 billion yearly.

Puerto Ricans are generally well informed and politically sophisticated with participation in elections exceeding 85 percent of registered voters. The Island's political status, the present Commonwealth and the Statehood and Independence alternatives, is strongly debated and preference for a particular status has a bearing on most decisions made by the Government and the people. It is therefore necessary to attain a general consensus as to goals in agriculture and how to attain them, irrespective of political status preferences, so that all sectors can collaborate effectively without constant changes in plans and programs. The need for producing locally as much food as possible can, and should be, an over riding consideration since a viable agriculture is possible with any of the three forms of political status. An inefficient agriculture could be protected under any status by subsidies, tariffs or regulations as the case may be, but consumers and, or, tax payers would be penalized. On the other hand, an efficient agriculture would require only limited help in addition to the protection offered by the high cost of transporting imported food. A viable agriculture is important economically, socially, politically and psychologically, especially for an island which can be isolated from its source of imported food.

Forty years ago, Puerto Rico had an agricultural economy based primarily on sugarcane and, to a lesser extent, on coffee, tobacco and cattle. Most of the food, with the exception of rice, beans and codfish, was produced locally. At that time the Government started a vigorous, successful effort to develop industries and tourism, the construction industry boomed, government grew, and there was a large exodus of laborers to the United States Mainland. This resulted in a massive exodus of capital and of the best human resources from agriculture with the less trained, less motivated people remaining on the land.

In 1950, agriculture provided 215,000 jobs (36% of total employment) and contributed 18% of the national product compared to 40,000 jobs and 5% of the national product at present. Sugarcane production is only 10% of the 1952 level, tobacco production has almost disappeared, whereas coffee remains stable producing about 3/4 of local consumption. On the other hand, production of milk, eggs, poultry and pigs, based on about 500,000 tons annually of imported food, has more than doubled over this period (Table 1) - (Anonymous 1978, 1982).

Puerto Rico imports about $1.2 billion of food yearly, with a retail value of $1.8 billion, and about $400 million of wood products. Agricultural production at the farm level is valued at about $580 million with a retail value of about $1.2 billion. About 40,000 persons are directly employed in agriculture on a yearly basis.

Agriculture at present is generally characterized by low yields, outmoded technology, inefficient government subsidies, high production costs, older farmers (average 55 years and 5th grade education), inefficient marketing systems and a negative attitude on the part of technicians, farmers, leaders and the general public.

Puerto Rico at present constitutes an almost unique example of a country which during the past 40 years has industrialized rapidly, while paying little attention to its agriculture, and is now attempting to modernize it.

If agriculture is to survive without continued massive subsidies, it must be completely modernized to bring it in line with the Island's progress in manufacturing, tourism and construction,and with the aspirations of its people,and to enable it to compete with imports from the highly efficient agriculture of the United States or from Latin America where land and labor costs are low. Table 2 (Vicente-Chandler 1978, and Anonymous 1977) shows how yields of the various crops can be sharply increased by the use of modern technology. To achieve these goals all practices must be applied at the right time and in a proper manner as a "package" or system.

Although use of modern techniques usually precludes intercropping, except as noted later, full use should be made of the year-round growing weather to produce 2 or more crops yearly.

If necessary, Puerto Rico could be self-sufficient in food production with only limited, but at present unrealistic, changes in consumption patterns. Table 3 (Vicente-Chandler 1974) shows a combination of agricultural enterprises, among many other possibilities, which could provide all the food required by the Island's present population. By using more labor intensive techniques, also not realistic under present conditions, the Island could provide the basic food needs of some future generations.

Food production should be based on making full use of the natural resources of soil and water and year-round growing weather. Efficient agricultural production based on optimum use and conservation of natural resources has a strong multiplier effect on both the economy and employment. It is estimated that every dollar at the farm level results in an increase of $2.50 in the national product and every direct job in agriculture results in the creation of at least another job.

Puerto Rico has excellent resources of soil and water and year-round growing weather, a good infrastructure, adequate capital, well-trained young people, an excellent market, the required technology and entreprenurial capacity as well as the public support necessary to create a modern agriculture based on 270,000 acres of mechanizable lands, 600,000 acres of deep, partially mechanizable soils in the humid mountain region and a steeper 300,000 acres which could produce almost all the wood products now imported, with over a million acres remaining for natural forests, wildlife and recreation.

WATER RESOURCES

Information on the water resources of the Island is limited and there are discrepancies in that available from different sources, particularly as regards aquifers.

Annual rainfall varies from 25 inches in the Southwest to 200 in the rain forests of the Northeast (Figure 1).

Islandwide, annual rainfall averages 75 inches (12,000 mgd) of which 46 inches (7,320 mgd) are lost by evapotranspiration, 23 inches (3,700 mgd) reaches the rivers and 6 inches (980 mgd) the aquifers. Of the water in aquifers, 280 mgd are pumped for agricultural, urban and industrial uses and 700 mgd are lost in the ocean. Of the water in rivers, 760 mgd are utilized for industrial, agricultural and urban purposes, (60 mgd are diverted from the North to the South coast) and 2,940 reach the ocean (Anonymous 1980).

Annual evapotranspiration potential varies from 35 inches in the highest mountain region to 65 inches in the dry coast (Figure 2). In the mountain region, average rainfall exceeds evapotranspiration potential throughout the year (Figure 3) although there are prolonged droughts during some years (Anonymous 1980).

Figure 4 shows the location of the major rivers and reservoirs of Puerto Rico.

Table 5 summarizes information on the reservoirs of Puerto Rico, which can hold a total of about 254,000 acre-feet of water. Possible new reservoirs with a total of 436,000 acre feet of storage are shown in Table 5, which, together with a proper distribution system, could supply all the water needed by all areas of the Island for the foreseeable future (Anonymous 1980). In addition, secondary treatment of approximately 400 mgd of sewage water could make part of it available for agriculture.

Water Resources for Agriculture

The humid mountain region

Most of the land area of Puerto Rico lies in the humid mountain region where average rainfall exceeds potential evapotranspiration throughout the year (Figure 3).

All major crops now produced or adapted to this area (coffee, plantains, bananas, citrus, cocoa, pastures and woodland) can tolerate periodic droughts if grown on deep soils of good, physical condition. Small ponds, springs and wells could be used for limited acreages of ornamentals and specialty crops and for raising pigs and poultry.

Humid coastal areas

Sugarcane, pineapples and pastures for dairy and beef cattle are the main crops in these areas with some bananas, plantains, root crops and pigeon peas. All these crops do well in this area without irrigation but require good drainage systems as well as protection from flooding in some areas.

Rice is grown in some valleys and has a good potential for expansion. Following is a brief discussion of the availability of land and irrigation water in the humid coastal areas for rice production which requires a steady supply of water in order to produce 2 crops yearly.

The valleys east of San Juan to Fajardo are densely populated and all water resources in this area are, or will soon be, used for urban or industrial purposes.

West from San Juan to Arecibo there are 4 river valleys with a total of 18,000 acres well adapted to rice production, although some will remain in pastures for dairies or in other crops. The minimum flow, (exceeded 90% of the time) of the Arecibo, Manatí (Gómez,1984) and Cibuco rivers, (Torres González and Díaz, 1983) can provide their respective valleys with sufficient water for 6,000, 5,000 and 2,000 acres of rice, respectively (Table 6). The aquifers of this region can provide an additional 100,000 acre feet of water yearly but most of this water will be needed for urban and industrial uses.

The San Juan Metropolitan Area, with over 1 million inhabitants, will soon require water from the two large reservoirs (Dos Bocas and Caonillas) on the Arecibo River (Figure 4). Canals or pipe lines from these reservoirs to San Juan would permit use of most of the water resources of the North Coast with a total of over 450 mgd compared to 200 mgd required by the Metropolitan Area by the year 2000 and 100 mgd required for irrigating 12,000 acres of rice.

On the West Coast, the Añasco and Culebrinas rivers (Quiñones et al., 1984) (Table 5) have enough water to irrigate 6,000 acres of rice in the level lands in their valleys and for 6,000 acres of other crops on the more rolling lands. Irrigation is necessary in this area, which has a marked dry season from December through March, in order to obtain good yields and quality of citrus, plantains, bananas and others, but is not essential for sugarcane since the dry season coincides with harvesting and helps to maintain a high sucrose content in the cane. There is little water in the aquifers of this area.

The Guanajibo River has enough water (Table 7) to irrigate 2,000 acres of rice and it is estimated that aquifers in this valley can provide enough water to irrigate an additional 6,000 acres.

On the East Coast, aquifers are very limited and are needed for industrial and urban use. However, the Fajardo, Humacao (Table 6) and other small rivers could be used to irrigate about 6,000 acres of rice in these valleys. Rainfall is very high in these valleys and high yields of bananas, plantains, yams, taniers, citrus, cocoa, sugarcane and pastures can be obtained without irrigation.

Semiarid South Coast

Average annual rainfall varies from 25 to 50 inches (Figure 1), evaporation is high (Figure 2) and there is a marked, well-defined dry season from December to April followed by moderate rainfall until August to October when rainfall is usually abundant. As a result, only range type beef operations and short-term crops such as pigeon peas, corn and sorghum planted during the wet season are possible.

With irrigation, however, a wide range of crops such as sugarcane, mangos, tomatoes, melons, peppers, cabbage, onions and others can produce high yields of excellent quality.

The numerous rivers in this area (Figure 4) carry little or no water during the dry season and are, therefore, of little use for irrigation.

The Lajas Valley in the Southwest has limited aquifers but has an excellent irrigation system with water from the Guayos, Luchetti and

Loco reservoirs (Figure 4 and Table 4). This system can provide about 35,000 acre-feet of water for use during the 5-month dry season, enough to irrigate about 8,000 acres.

On the other hand, if these reservoirs are managed so as to provide a uniform supply of water throughout the year, they can catch and deliver for irrigation about 70,000 acre-feet yearly, enough for optimum irrigation of about 9,000 acres of rice (Quiñones et al., 1979).

The following appears to be a reasonable approximation of the water available on the South Coast from Guánica to Maunabo (Morris, 1977) which does not include the Lajas Valley.

	For agriculture	Urban and industrial	Total
1. Water from irrigation systems	78 mgd (86,000 acre-feet)	41 mgd (45,000 acre-feet)	119 mgd (131,000 acre-feet)
2. Pumping from aquifers	145 mgd (159,000 acre-feet)	42 mgd (46,000 acre-feet)	187, mgd (205,000 acre-feet)
Total	223 mgd (245,000 acre-feet)	83 mgd (91,000 acre-feet)	306 mgd (336,000 acre-feet)

Recharge of aquifers is estimated at 160,000 acre-feet (145 mgd) from rivers, 13,000 acre-feet (12 mgd) from rainfall and 93,000 acre-feet (85 mgd) from irrigation, for a total of 266,000 acre-feet (242 mgd) with 58,000 acre-feet (55 mgd) flowing into the ocean. Much of this apparent loss is necessary to prevent saline intrusions into the aquifers which are already occurring in limited areas suggesting that little, if any, additional water can be pumped from the aquifers (Morris, 1977).

As irrigation practices are improved, present recharge of aquifers from over-irrigation, which totals 93,000 acre-feet (85 mgd) yearly, will be reduced. Therefore, increased irrigation efficiency will not proportionally increase the acreage which can be irrigated since it will result in a decrease in the water available in the aquifers (Morris, 1977).

About 5 acre-feet are required yearly for each acre of intensively cropped irrigated lands, assuming that 18 inches of the annual rainfall are utilized by the crops, that evapotranspiration averages 0.15 inches daily, that crops are grown the year-round, and that irrigation efficiency is 70%.

The 223 mgd (245,000 acre-feet) of water now used for irrigation provide 85 mgd (93,000 acre-feet) of wasted water to recharge the aquifers. If irrigation waste is reduced by half through the use of more efficient irrigation methods, probably only about 180 mgd (200,000 acre-feet) will be available for irrigation, enough for about 40,000 acres. If part of the land is used only during the winter season for vegetables and all water, including some treated sewage water, is used and is optimally managed, it may be possible to irrigate up to 60,000 acres on the South Coast. Increased transfer of water from the humid region could double the acreage under irrigation.

The Puerto Rico Department of Natural Resources and the Aqueduct Service should complete a study of all water resources of the Island in cooperation with the U.S. Geological Survey and the Army Corp of Engineers, if necessary, and prepare a plan for their use and conservation. The local government should also assign the responsibility for use of the Island's water resources to one agency and provide incentives for establishing efficient irrigation systems.

The Federal and local government should jointly fund construction of additional dams and water distribution systems.

SOIL RESOURCES

Puerto Rico has more than 300 soil series (Roberts,1938) representing eight of the nine major groups of the World. For planning purposes, this wide range of soils has been grouped into 12 categories (Vicente-Chandler, 1978) considering the most important factors which determine their adaptability for production of the different crops: topography, soil depth and physical condition, climate,and availability of water from rainfall or irrigation. Soil fertility was not considered since an intensive agriculture is deemed necessary and the natural fertility of the soils is low in comparison to the demand for nutrients by high yielding crops. Soil acidity was also not considered since it can be corrected by liming and there is an abundance of limestone on the Island.

Table 7 shows the area of each of the 12 soil groups and the best adapted crops (Vicente-Chandler, 1978). There are about 270,000 acres of mechanizable lands available for intensive mechanized agriculture (Groups A, B, H, I) and about 107,000 of gently sloping lands in the humid region (Group C) and 39,000 (Group J) in the semiarid region. There are about 485,000 acres of deep soils in the humid mountains (Group D) suited to crops which are soil conserving or can be grown so as to be soil conserving, do not require mechanization and can tolerate periodic droughts,and 280,000 acres of medium deep soils (Group E) are suited to commercial forests; with remaining lands for wildlife, recreation, etc.

Need for Concentrating Commodities in Different Areas

The various agricultural commodities should be concentrated in the areas best suited for their efficient production considering maximum utilization and conservation of the limited natural resources of the Island and other possible uses for the areas.

The soils suited to agriculture in the humid hill and mountain region (about 600,000 acres in Groups C and D) should be used for crops that are soil conserving or can be grown in such a way as to be soil conserving, that do not require complex mechanization and can therefore be grown as economically as in mechanizable areas, and that can tolerate the periodic droughts which occur in this region despite generally abundant rainfall. Pastures for milk and meat production, coffee, citrus, plantains, bananas and cocoa, meet these requirements. To the extent that these crops are grown on mechanizable lands with many other alternative agricultural uses, the potential of the humid hill and mountain region is diminished as is the agricultural potential of the Island as a whole.

Concentration of the different agricultural enterprises in the most appropriate areas not only makes better use of the Island's resources, but also makes it easier to provide the farmers with the special services, materials and facilities required by each crop.

The concentration of crops in specific areas can be encouraged by educational efforts, by incentives and credit, by constructing facilities to provide marketing and other services to farmers, by specifying the uses to be made of Government lands leased to farmers, and other means. It is obviously impossible to locate all the various enterprises in the areas best suited to their production but efforts should be made to attain this goal.

Reasons for locating the different crops in specific areas are discussed below.

Commodities for Mechanizable Lands (Groups A, B, H, I - 270,000 acres)

Sugarcane

This crop requires complete mechanization and an abundance of water from rainfall or irrigation during the growing period with relatively dry weather during the harvest season of January to April. For this reason, sugar production should be concentrated on soils of Group A in the valleys of the West Coast, where rainfall is abundant during most of the year and there is a well-defined dry season during the harvest season, and on irrigated soils of the semiarid South (Group H) which are too heavy for optimum vegetable production.

Rice

This crop requires complete mechanization, near level, heavy soils and a continuous abundant supply of irrigation water in order to produce two high yielding crops yearly. For this reason, rice should be grown on the valley soils of the humid region (Group A) where there is abundant river water which can be pumped at a low cost and is not being utilized, and with irrigation on the heavy soils of the Lajas Valley (Group H) which are not suited to more profitable crops.

Vegetables

These crops require near level lands, friable soils, and a dry climate with irrigation. They should therefore be grown on soils of

Group I in the semiarid South Coast using the most modern systems of irrigation so as to obtain highest yields and quality.

Pineapples

This high income crop requires complete mechanization, porous soils of excellent physical condition and does not require irrigation where annual rainfall exceeds 60 inches. They should therefore continue to be grown on the mechanizable red soils (Group B) near the packing and processing facilities on the North Coast.

Pigeon peas

Production should be completely mechanized including harvesting. Irrigation is not required where rainfall exceeds five inches monthly during the growing season. This crop should be grown on the red soils (Group B) of the North Coast not required for pineapple production, and on the irrigated mechanizable lands of the South Coast not suited to vegetable production (Group H).

Hay

Efficient production requires mechanizable lands, a dry climate and irrigation. Hay production should therefore be concentrated on the heavy mechanizable soils of the semiarid region (Group H), not suited to higher value crops.

Grain

Beans, soybeans, corn, sorghum or cotton may be grown on mechanizable lands (Groups A, B, H and I) with sufficient rainfall or irrigation and where higher income crops cannot be grown and in rotation with such crops as vegetables and rice.

PUBLISHERS NOTE:

THE FOLLOWING PAGE WAS OMITTED
IN THIS PRINT. # 89 .

fertilizer can be applied with special tractors or by air. Furthermore, it has been shown that both dairy and beef cattle can be very productive on steep, well fertilized pastures in the humid mountains. (Caro and Vicente-Chandler, 1980 and Vicente-Chandler et al., 1974 and 1983). Milk production should be concentrated on the less steep lands of Group C and Group D and meat production in Group D.

Coffee

Intensively managed coffee protects the soil against erosion, as shown above, and is drought tolerant. Plantations last for 20 years or more and require little mechanization since weeds and pests are controlled by pesticides applied with knapsack sprayers and the coffee beans are harvested using nets. Coffee production should be concentrated on soils in Group D.

Citrus

These crops offer the soil less protection than coffee and should therefore be grown with a cover crop or with strip cropping supported by diversion ditches. They do not require complex mechanization nor irrigation under most conditions in the humid mountain region and should be concentrated on soils of Groups C and D.

Mangos

Mangos require little mechanization but must be grown in the semiarid region since fungus attacks sharply reduce yields in humid areas. They should be grown on gently rolling soils (Group J) with drip irrigation and a cover crop for erosion control.

Plantains and Bananas

If intensively managed, plantains can produce 3 successive crops and bananas 10 or more, without replanting. These crops require little mechanization, are drought resistant and if closely planted without plowing the land, complemented by strip cropping and diversion ditches, can provide excellent erosion control as shown above. Plantains and bananas should be planted on soils of Groups C and D. Bananas for export can also be grown on soils of Group A or on irrigated soils of Group H and I.

Root Crops

These crops should continue to be grown in relatively small fields on porous gently sloping soils of the humid mountain region (Groups B and C) with partial mechanization. Diversion ditches, strip cropping and rotation with grasses should be practiced for erosion control.

Cocoa

This crop requires little mechanization, does not need irrigation in the humid region and erosion can be controlled by strip cropping and diversion ditches. Current studies indicate that intensively managed, sun grown cocoa can produce high yields on soils of Groups A and C.

Oil Palm

Oil palms require little mechanization, can be grown with strip or cover cropping and diversion ditches for erosion control and can tolerate periodic droughts. It is likely that they may yield most heavily in warmer areas near the coast. If oil palms prove to be commercially viable in Puerto Rico, they can be grown on soils of Groups B, C and D.

Commodities for Other Lands

Commercial Forests

Forests offer excellent protection to the soil, are drought tolerant and require little mechanization. Planting and weed control during the first year are done by hand but there are efficient methods for harvesting the wood even on very steep slopes. Although trees can be grown commercially in any area with deep soils and abundant rainfall, they should be concentrated on the steeper, deep soils of the humid mountain region (Group E, and some of Group D) not suited to other uses.

Poultry, Pigs and Ornamentals

These enterprises require little land and can be located in almost any region near processing facilities, preferably in the cooler mountain region.

Aquaculture

Some lakes can be used to raise fish. Level, heavy soils, with limited uses for agriculture and an abundance of water, can be used for intensive fish production. The Caño Tiburones area near Arecibo seems promising.

AGRICULTURAL COMMODITIES

Following is a brief discussion of the various agricultural commodities produced in Puerto Rico or having a potential for local production. Their soil and water requirements and effects on conservation of these resources have already been discussed.

Sugar

About 103,000 tons of raw sugar and 8 million gallons of molasses are produced yearly and about 37,000 tons of sugar and 42 million gallons of molasses are imported. Most operations are mechanized but inefficient employing about 5,000 on a yearly basis. Yields average less than 2 tons of sugar/acre, compared to over 4 tons produced on these lands 30 years ago, due to inefficient drainage and irrigation systems, inadequate pest control, poor timing of burning and harvest operations and poorly maintained, inefficient sugar mills. The Sugar Corporation operates the five mills and about 20% of the 70,000 acres of cane land. Accummulated debts exceed $500 million and losses continue at about $20 million yearly.

Technically, there is no reason why Puerto Rico cannot produce sugar economically for the local market at the current U.S. price of about 21 cents/pound. Forty thousand acres of intensively managed sugarcane yielding 40 tons of cane/acre (Anonymous, 1975 and 1977) could supply the local market for sugar (140,000 tons yearly) or provide all the molasses (45 million gallons of high test molasses equivalent to 60 million gallons of final molasses) needed by Puerto Rico's rum industry, which contributes over $200 million yearly to the Island's treasury from reimbursed Federal taxes.

Such a modern sugar industry could be created by investing about $70 million in Government funds over a 7-year period to pay for leveling lands, establishing efficient drainage and irrigation systems, modernizing the sugar mills and planting new high yielding varieties adapted to the different ecological regions. The industry must be returned to private industry and labor contracts similar to those of other agricultural enterprises negotiated. The alternative is to continue the present inefficient operation with heavy losses and subsidies or cease production.

A return to hand harvesting, as practiced in Florida, Louisiana, Australia and by some Puerto Rican farmers, is possible in some cases. This could result in higher employment, about 4,000 jobs compared to 2,500 jobs with completely mechanized efficient operations, less investment in expensive equipment and an increase in the sucrose content of the cane as compared to the present practice of burning and often delayed mechanical harvesting. A well-trained laborer can harvest 4 tons of cane a day at a cost of $7 plus $3 for loading equivalent to $400 for an acre producing 40 tons, compared to $280 charged by the Sugar Corporation for harvesting and loading mechanically. The higher cost of hand cutting could be compensated for by a higher sucrose content.

The growing of so called "energy cane" is not a reasonable alternative for an island with 12 persons/acre of mechanizable land, all 270,000 acres of which could supply only about 17% of the Island's energy needs while increasing dependence on imported food. Furthermore, the economics of such an operation are questionable and the effect on the environment largely unknown. Bagasse, of course, can continue to be burned as a source of energy.

Rice

Puerto Rico consumes about 3.1 million hundredweights of milled rice yearly imported from the United States except for 100,000 hundredweights produced locally.

Rice production in Puerto Rico must be completely mechanized and use the most modern technology in order to compete with imported rice and therefore only one job is created for about every 50 acres of rice.

A viable rice industry in Puerto Rico is based on obtaining two crops yearly, each averaging 5,000 pounds of rough rice/acre, continuous production which reduces investment in machinery and facilities which can be used year-round, and the cost of importing rice (about $2.50/hundredweight) which favor the local industry (Vicente-Chandler et al., 1977, 1985). In the humid region and the semiarid irrigated Lajas Valley, there are approximately 40,000 acres of level heavy soils with sufficient water for optimum irrigation of rice the year-round and capable of supplying 80% of the local market.

The local rice industry was started in 1978 on land owned by the Government on the North Coast. Rather than utilizing already tested techniques (Vicente-Chandler et al., 1977), studies were carried out, changes were constantly made in the program, and the lands were precision leveled at a high cost in time and money. As a result, only 2,500 acres are now in production with an additional 3,000 acres almost ready to produce. A modern rice mill established at Arecibo and capable of processing all the rice produced from 18,000 acres planted twice yearly, is operating profitably by combining imported with locally produced rice and has captured over 20% of the local market.

The economic viability of treating rice straw for cattle feed with sodium or ammonium hidroxide to increase disgestibility from 30 to about 50% should be studied as should the use of treated sewage water for irrigation. The use of locally produced rum distillery slops, pumped into the main canals and distributed in the irrigation water, to provide all the nitrogen and potassium required by 5,000 acres of rice has been found to be technically feasible. Rotation of rice with sorghum, soybeans or cotton may be desirable.

The local Government should continue to establish and maintain the irrigation systems with a reasonable charge to the farmers, guarantee a minimum price equivalent to the U.S. target price or to $2.50/hundredweight more than the U.S. market price and subsidize a private company to provide airplane service for pesticide and fertilizer applications until there is sufficient acreage for an efficient operation.

Vegetables

Demand for vegetables has increased rapidly and imports now far exceed local production (Table 1), which is traditionally from small fields with low yields and quality. Lack of a continuous supply of good quality local produce has resulted in increased imports, largely from the Mainland where produce of good quality is available the year-round.

There are about 24,000 acres of soils of excellent physical conditions with irrigation in the semiarid south coast suited to optimum production of a wide range of vegetables. Approximately 7,000 acres could supply the local demand for such fresh vegetables as tomatoes, peppers, melons, pumpkins, okra, cucumber, onions, and others (Vicente-Chandler, 1978).

The local market for fresh vegetables is protected by the cost of shipping refrigerated produce from the Mainland (about 6¢/pound) and consumers are willing to pay higher prices for recently harvested produce. Although most vegetables can be grown successfully during the cooler dry winter months, (Anonymous, 1977) yields and quality decrease during the warm humid season, precisely when an abundance of low priced vegetables from the Mainland are available. Also, supplying the local markets with fresh vegetables throughout the year requires careful planning in order to balance supply and demand since even a small surplus can shaply reduce prices since the only alternative market is on the Mainland where small, unforeseen shipments are difficult and expensive to market.

On the other hand, there is a good opportunity during the winter months for producing a variety of vegetables, especially during "windows" between peak production in Florida, Mexico and California. Production for export must be on a large scale with well planned plantings, product quality control and full use of the low rates for refrigerated vans returning to the U.S. Mainland (except for refrigeration, it costs almost as much to ship an empty as a full container).

Seven years ago the Government of Puerto Rico started a modern vegetable industry on about 5,000 acres on the South Coast by leasing lands and providing credit and facilities to two large Israeli companies and 13 local farmers. Approximately 2,500 acres now have modern drip irrigation systems and two packing plants are in operation. Production for export is mainly honeydew melons, tomatoes and peppers whereas onions, watermelons, pumpkins, eggplant and others are sold locally. Yields and quality are as high as in the most efficient farms in competing areas of the United States and Mexico. The advantages of a favorable climate, abundant well-trained laborers, and low cost, almost daily shipping to the Eastern United States (costs of shipping from Puerto Rico to New York are similar to freight costs from Florida to New York) are partly offset by higher labor costs due to local laws and no migrant laborers.

It is possible to plant large acreages of various vegetables for the winter market while also supplying the local market during this season. Sorghum, corn, soybeans or cotton for local use can be grown during the summer taking advantage of the irrigation system and of any residual fertilizer.

It is also possible to produce some vegetables for the local market throughout the year by carefully timing the plantings. The production of vegetables for canning in competition with imported products does not appear to be viable at present.

Use of drip irrigation is important to obtain high yields and good quality vegetables and to efficiently use the expensive, scarce irrigation water. Sprinkler irrigation increases problems with diseases and strong winds during the day limit it's use to evening and the early morning hours. The irregular surface of much of the land, the high cost of leveling and problems with some soils, make surface irrigation of vegetables difficult.

In order to increase vegetable production, which creates one direct job for about every 5 acres, the local government should continue to lease land to farmers to plant vegetables and should guarantee the first plantings of new vegetables or those using new technologies for the first time, against losses.

Pineapples

About 42,000 tons of pineapples are produced yearly on 3,000 acres harvested annually out of 4,000 planted to pineapples by the Land Authority, a Government agency which also operates the packing and processing plant and almost invariably loses money. About 3,000 tons of fresh fruit are exported yearly, 4,000 tons are sold locally and 36,000 tons are processed for juice. Quality of the juice sold under the "Lotus" brand is considered the standard for the industry worldwide.

Production is low, about 14 tons/acre, but with modern technology more than 40 tons of pineapple are produced/acre in the plant and ratoon crops combined (Anonymous, 1977).

The demand for fresh pineapples on the east coast of the United States could be supplied by Puerto Rico. Almost daily service with refrigerated vans at low cost makes it possible to harvest the pineapples at a more advanced stage of maturity, resulting in better quality fruit.

There are about 30,000 acres of excellent pineapple soils (Group B) near the packing and processing facilities on the North Coast with sufficient rainfall so that no demands are made on the water resources of the area. Erosion is not problem on these near-level lands if contour farming and terracing are practiced. Pineapples are labor intensive, creating one job for about every 6 acres of plantings.

The Government should sell the pineapple plant to a private enterprise which must develop market outlets for the fresh fruit in the Eastern

United States, and use modern technology in a large scale operation. It should also lease all the pineapple lands it owns to private farmers and help them obtain credit by guaranteeing loans.

Pigeon peas

About 110,000 hundredweights of pigeon peas are produced yearly and 15,000 are imported. About half are canned.

Pigeon peas are grown mostly on about 15,000 acres in the semiarid region during the rainy season, mostly on small farms on steep lands. Pigeon peas bear only from November through March. Cultivation and picking is by hand, yields average only 500 pounds/acre, and the highly erodible soils have contributed to the rapid siltation of critical reservoirs.

Pigeon peas can be grown in competition with imports only by using modern technology in mechanized operations coordinated with the canneries which preserve them for the off season. Techniques have been developed for producing high yields of pigeon peas and approximately 2,000 acres are now grown in mechanized operations on irrigated lands averaging over 20 hundredweights/acre. Pigeon peas can also be grown successfully without irrigation in the humid areas of the Island (Rivera and Irizarry, 1984, Anonymous, 1977). About 7,000 acres of such plantings could supply the local market with favorable effects on soil conservation and water resources but employment would be sharply reduced from about 1,500 at present to 500 and many small farmers adversely affected. There is no potential for expansion beyond the local market. The alternative is to continue to subsidize prices and, or, try to regulate foreign imports by sanitary regulations.

Grains

Approximately 500,000 tons of feed for cattle, pigs and poultry are imported yearly, mostly from the United States Mainland, and none of the ingredients are produced locally. Grain crops, especially sorghum, could be grown on about 40,000 acres not suited to higher income crops and in rotation with vegetables during the off season, or with rice.

Yields of over 4,000 pounds of sorghum or corn have been obtained per acre with two crops produced yearly. Sorghum and corn are sold locally at about 2.5 cents more/pound than in the Mainland, due to shipping costs. There are varieties of white sorghum that can be made into flour which can substitute for part of the wheat flour in bread. It is also possible to produce 2,000 pounds of soybeans or two bales of cotton per acre with irrigation but these crops require processing facilities not now available.

Grain crops produce a low income, create few jobs and face strong competition from imports and should therefore be limited to areas with no better alternative uses or in rotation with higher income crops.

Milk

About 374 million liters of fresh milk are produced yearly, 6 million liters of UHT milk are imported, and the equivalent of 150 million liters are imported dry or condensed. Increasing quantities of UHT milk, which can be stored without refrigeration, are being imported and some is produced locally.

There are about 600 first class dairies with approximately 150,000 acres, 130,000 of which are in pasture and 10,000 in grasses for cutting. There are about 110,000 cows averaging 12 liters daily, fertility problems are common, mastitis is widespread, and bacterial counts in the milk are often high. Excessive quantities of expensive, imported concentrates are used, an average of over 1.5 pounds/liter of milk (320,000 tons yearly) at a cost of 19 cents/liter with a farm price of 49 cents.

On the other hand, experiments and large scale tests on private farms (Caro et al., 1972, 1980) have shown that the first 10 liters of daily milk production can be produced without concentrates if cows are grazed on well-fertilized, intensively-managed tropical grass pastures with additional production supplemented at the rate of one pound of concentrates/liter. Costs could be decreased by about 6 cents/quart and imports sharply reduced (Vicente-Chandler et al., 1974, 1983).

There are hundreds of thousands of acres on moderate slopes in the humid mountain region which, if planted to improved grasses and well-fertilized, can carry one cow/acre throughout the year. Pastures help conserve steep soils, are drought tolerant, and little mechanization is required since cows graze even very steep lands and fertilizer can be applied with special tractors or by air.

It is essential to improve efficiency in milk production, improve quality control, establish effective systems for disposing of manure and base production on well-managed grass pastures. Production must be limited to the local market for fresh milk, which is protected by the high cost of imports, with an increasing demand for UHT milk. Employment can be maintained at about 5,000. The alternative is continually rising prices and increased imports of UHT milk.

The Puerto Rico Government should provide incentives for planting improved pastures in the humid hill lands and for fertilizing them in order to decrease imports of concentrates and help conserve soil and water in this region and should regulate the industry to increase milk quality.

Hay

Approximately 10,000 tons of poor quality hay are produced yearly on about 2,000 acres and 4,000 tons are imported at a high cost. Hay is fed to horses and calves and to other cattle during droughts.

Hay production should be increased for the local market and concentrated on about 5,000 acres of well-fertilized irrigated grasslands in the dry region so that it may be dried in the sun.

Beef

About 38 million pounds of beef are produced locally and 76 million pounds are imported fresh or frozen, about 28 million from the United States and 48 million from foreign countries. Much of the local beef comes from the dairy industry or from small farmers which graze a few head or tether them along roadsides or in neighboring farms. Only about 200 farms of more than 100 acres with a total of 160,000 acres and 70,000 head, produce beef commercially.

About 50,000 male calves and 25,000 heifers not needed as replacements are produced yearly in dairies and almost all are slaughtered soon after birth. If 50,000 were grown to 800 pounds they would produce 20 million pounds of beef compared to 3 million when slaughtered at birth.

Over 1,000 pounds of gain in liveweight can be produced per acre yearly with intensively managed, well fertilized grass pastures in the humid mountain region (Vicente-Chandler et al., 1974, 1983). Growing out young calves or raising replacement heifers for the dairies can be moderately profitable on such pastures (Vicente-Chandler et al., 1983) but cow-calf operations are not profitable if all costs are considered although use of culled dairy cows, which can nurse two calves, can reduce costs. Range type operations on relatively large farms in the semiarid region can be moderately profitable if only cash expenses such as those for fencing, maintaining the water supply, rotation grazing and well-planned burning of pastures to control weeds are considered.

Beef production should be limited to farms or areas of farms not suited to more profitable crops, since it creates few jobs and provides a low income. Only a modest increase in beef production for the local market is foreseen with employment of about 2,500. Pastures are soil and water conserving and have no unfavorable impact on the environment if properly managed.

Local Government incentives should be provided for raising dairy calves and using culled cows to raise two calves each as well as for planting grasses on hill lands.

Coffee

Approximately 250,000 hundredweights of market coffee are produced and about 140,000 are imported yearly. Most of the coffee is produced on about 100,000 acres of shaded, semi-abandoned plantations with one of the lowest per acre productions in the world (González-Villafañe et al., 1971).

Federal law authorizes the Commonwealth of Puerto Rico to set a tariff which protects the local coffee industry from imports. The current local farm price for first class market coffee (before roasting) is $186 per hundredweight. Only the Commonwealth Government can import coffee, which it purchases on the world market at $120 to $140/hundredweight, (a price range established by an agreement between the coffee importing countries) and then sells to local roasters at a profit.

A Government sponsored rehabilitation program for the coffee industry, based on modern techniques (Vicente-Chandler, 1984) and including incentive payments for new plantings, donations of fertilizers and hurricane insurance, has been very successful. Coffee produces a commercial crop 3 years after transplanting but can be intercropped with plantains to provide income during the first year or so. About 10,000 acres of intensively managed coffee growing in full sunlight have already been established with yields of 1,200-1,500 pounds/acre. Harvesting with nets, a locally developed technique (Vicente-Chandler et al., 1969, 1984), reduces picking costs from 60 to 20 cents/pound and prevents loss of berries. With this technique, already used on about 20 farms, costs are only about $90/hundredweight and it is possible to produce coffee for the export market.

Coffee is adapted to steep lands in the humid mountain region since it is soil conserving and does not require mechanization or irrigation. It is labor intensive, with one job per 5 acres of plantings, and is suited to family-size operations if processing facilities on the larger farms are used.

Coffee production should be increased to supply the local market from 30,000 acres of intensively-managed plantings (6,000 jobs) and, thereafter, gradually increased for the export market.

The local government should provide incentives for increased use of plastic nets and for establishing new intensively managed plantations and should maintain tariffs at such a level that efficient farmers can make a reasonable income.

Plantains

About 330 million plantains are produced on about 15,000 acres, mostly in small plantings in the humid mountain region. None are exported or imported.

Techniques for the intensive production of plantains are being rapidly adopted resulting in yields of 35,000 fruits/acre for the plant crop and 25,000 fruits for the ratoon crop. Intercropping with vegetables is possible during the first months. If plantings are well planned, stable year-round production and a uniform supply to consumers at reasonable prices are possible (Espinet et al., 1973). Plantains are suited to family-size farms in the humid mountain region since they provide a high income, can be grown with proper conservation (Vicente-Chandler et al., 1966, 1980), do not require mechanization and are drought tolerant. Plantains, as well as bananas, can go a long way towards producing the carbohydrate requirements of Puerto Ricans. One well-cultivated acre can produce as much carbohydrates as can an acre of high yielding potatoes or corn in the U.S. Mainland.

Plantings should be encouraged by continuing local government spray programs for control of leaf diseases, insurance against high winds, and short-term credit. Plantings should be limited to about 15,000 acres with employment of about 3,000 persons in order to supply the local market which will soon increase to about 450 million fruits yearly.

Bananas

Approximately 720 million bananas are produced locally and none are imported or exported. Most come from trees scattered throughout shaded semi-abandoned coffee plantations and are an important year-round source of income for coffee farmers. Yields are low and quality is poor due to careless handling of the fruit. Banana production from shaded coffee plantations is decreasing as these are abandoned in favor of new, well managed sun-grown coffee orchards.

High yields of excellent quality bananas can be obtained in the humid region or with irrigation in the semiarid areas if modern techniques are used. The local market can be supplied throughout the year with good quality bananas from about 7,000 acres of well-managed plantings in the mountain region providing about 900 jobs. Bananas are suited to hill lands since they can be grown with good erosion control, require little mechanization and can tolerate periodic droughts. A spray program for pests and insurance against high winds are essential.

Puerto Rico has a good potential for producing bananas for export. There are tens of thousands of acres in the humid coastal areas and in the semiarid South Coast with irrigation, where commercial plantings have produced as high yields and quality as the best plantations in Central America. Altho labor costs are much lower there, the banana companies usually must establish and maintain the infrastructure of roads, schools, health facilities, water and light, and must also pay taxes. In Puerto

Rico, on the other hand, the infrastructure is available and is maintained by the Government, income from agriculture is 90% tax exempt and there is political stability. Furthermore, there is almost daily, low cost refrigerated transportation to the United States. The local government could help develop a banana industry for export by providing incentives to a private concern capable of efficiently marketing the bananas. Intensive banana production provides one year-round job for every 5 acres.

Mangos

Almost all local production comes from trees growing wild and is generally of poor quality. About $1 million worth of mangos are exported to the Puerto Rican market on the Mainland and none are imported. A modern industry, (Anonymous, 1977) mostly for export, is now rapidly developing on rolling lands in the semiarid region with drip irrigation and creating one job per 12 acres of plantation. About 3,000 acres have already been planted, come into production at about 3 years,and after 7 years yield over 200 hundredweights/acre. A modern packing plant is already in operation and a cannery for mango halves and juice is being constructed.

There are more than 20,000 acres ideally suited for mango production and sufficient water is available for irrigation although considerable pumping will be required. It is expected that 10,000 acres will be planted by 1990 and wil' eventually produce mangos with a farm value of $80 million . Mango production is suited to small scale operations if they form part of a large project providing technical supervision and marketing facilities.

The local government could help by constructing facilities for treating mangos for control of the West Indian fruit fly so that they can be exported to the U.S. Mainland and providing incentives for a rapid expansion of export markets.

Citrus and Other Fruits

About 160 million oranges are produced locally and 31 million, as well as 4 million gallons of concentrates, are imported. About 6.6 million grapefruits are produced locally and 2 million are imported. Puerto Rico is the World's second largest producer of citron with about 89,000 hundredweights exported yearly.

Most citrus come from trees growing wild in old coffee plantations and production is decreasing as these are abandoned in favor of new coffee orchards. Although of inferior appearance, their juice is excellent.

Citrus for the local market can be produced in small well-managed orchards (Anonymous, 1977) in the mountain region and quite a number have already been established and are yielding well. About 7,000 acres of such orchards could supply the local market. Good erosion control is possible with strip or cover cropping supplemented by diversion ditches and one job is created for about every 6 acres of orchards. Puerto Rico also has a potential for producing citrus for export.

Papaya can produce high yields in the humid mountain region (Lloréns and Vicente-Chandler, 1976). Coconuts, on the coastal areas, and soursop, sapodilla, guava and other fruits in the semiarid region can also be produced for the local market.

Root Crops

Approximately 240,000 hundredweights of taniers are produced yearly and 175,000 are imported; 210,000 hundredweights of sweet potatoes are produced locally and 100,000 imported; 321,000 hundredweights of yams and 75,000 hundredweights of taro are produced locally and none are exported or imported; and 60,000 hundredweights of cassava are produced locally and 25,000 are imported (Table 1).

Almost all root crops are produced in small plantings in the humid mountain region and yields are generally low. However, high yields can be obtained when modern technology is used (Anonymous, 1977, Caro et al., 1968, Espinet et al., 1972, 1977). Production should be limited to about 8,000 acres for the local market where some root crops face strong competition from the Dominican Republic.

Some root crops can be intercropped. For example, research has shown that cassava yielded about 300 hundredweights/acre when used as a support for yams which yielded only about 10% less than with conventional wood and wire supports.

Production of root crops, except for sweet potatoes which require complete mechanization, should be continued mostly in small plantings in the humid mountain region using modern technology to obtain high yields and quality. One job is created for about every 5 acres of root crops grown under these conditions. Although root crops do not protect the soil against erosion, soil losses can be ameliorated by the use of diversion ditches, strip cropping, and long-term rotation with pastures.

Poultry

About 20 million dozen eggs are produced locally and 17.5 million are imported yearly. About 52.5 million pounds of poultry are produced locally and 142 million are imported. Approximately 160,000 tons of poultry feed are imported yearly and none is produced locally. Consumers pay considerably higher prices for locally produced eggs and poultry.

Almost all eggs and poultry are produced in vertically integrated operations similar to those on the Mainland (Pringle et al., 1973). Retail prices, however, exceed those of imported eggs and poultry since local production is inefficient and feed is expensive.

It is theoretically possible to locally produce eggs at competitive prices since excellent breeds and techniques are available, the cost of imported feed can be decreased somewhat, investment in facilities is relatively low due to the benign climate, and the cost of importing eggs and poultry is high.

Poultry production has relatively little economic impact on the Island since more than two thirds of production costs is for imported materials (Table 10) and efficient operations are not labor intensive. It seems logical, therefore, to increase production only to the extent of satisfying the market willing to pay higher prices for local products. Such production would employ about 1,000 persons and requires protection against occasional "dumping" of Mainland products at prices below production costs.

Pigs

Approximately 40 million pounds of pork are produced locally, and 73 million pounds are imported fresh or frozen and 28 million as hams.

There are about 35,000 pigs in commercial farms and about 200,000 in non-commercial operations (less than 10 sows or 50 piglets) and most pigs are slaughtered on the farm (Vargas et al., 1975). Approximately 60,000 tons of pig feed are imported yearly.

There is a good local market for fresh pork from pigs weighing about 120 pounds whereas imported pork is usually from animals weighing 200 pounds or more. As with poultry, local production theoretically could be competitive with imports.

Since production is based largely on imported feeds, no particular efforts should be made to increase production beyond the demand for fresh pork from rather small pigs, except for taking action to prevent "dumping". Pigs should continue to be produced for local consumption on rather small farms throughout the Island using as much slops from restaurants and local by-products as possible. About 1,000 persons can be employed in such an industry.

Ornamentals

About $12 million worth of ornamentals, mostly tropical foliage plants, are produced annually for export and the local market. The humid mountain region has an ideal climate for producing most ornamentals and the small amounts of water required can be obtained from small streams, farm ponds and wells. Relatively small farms can be organized through cooperatives or farmer associations with a central unit providing materials, technical supervision and marketing. Production of ornamentals should be expanded as far as markets permit since they occupy little land and are labor intensive.

Aquaculture and Mariculture

Two commercial projects are producing fresh water shrimp but have not yet been successful economically, altho they have shown the possibility of producing high, profitable yields. Some of the fresh water lakes can be used for intensive fish production. Local research with Tilapia shows that high yields are possible.

There is considerable land suited to aquaculture. The Caño Tiburones area with 6,000 acres of level lands, deserves special attention since the water level can be controlled by pumping and fresh, brackish, and sea water are available if a proper system of management is developed.

Mariculture offers opportunities in the shallow waters and reefs of the South Coast and technology developed in Hawaii can be adapted to local conditions.

The Federal government could help by assigning more funds for research and initial development. Results could have wide applicability throughout the Tropics and the Caribbean Basin in particular.

Commercial Forests

Puerto Rico imports about $400 million of wood and wood products yearly and, except for fence posts, almost none are produced locally.

About 300,000 acres of steep, deep soils in the humid mountain region not suited to agriculture are well adapted to commercial forests. Honduras pine can be profitably produced on these lands enabling the Island to almost attain self-sufficiency while creating about 5,000 jobs. There is also a good potential for producing hardwoods such as mahogany and teak.

Planting trees requires considerable labor and much is also later required for harvesting and processing. A well-planned program for establishing commercial forests involving farmers and the local and Federal governments could make an important contribution to the Island's economy and reduce unemployment. The local or Federal governemtns could provide funds to pay labor for planting trees. They could also help insure commercial forests against damage by hurricanes, especially if actuarial studies indicate that premiums could be high.

New Crops

Cocoa is not produced in Puerto Rico but research indicates that intensively managed plantings can produce high yields at low and medium elevations in the humid region.

Cocoa can be grown in small plantings with proper conservation, does not require mechanization or irrigation in the humid region and can be intercropped with plantains during the first 2 years. About one job would be created per 8 acres of plantings. The local market could be supplied from about 7,000 acres and the export market offers possibilities if modern technology is used.

Puerto Rico imports about 35,000 tons of cooking oil yearly and none is produced on the Island. Although no reserach has been conducted, the production of palm oil offers possibilities. Oil palms can be grown with a cover crop, require little mechanization, and appear to be adapted to the humid coastal areas. Potential production could be as high as 3,000 pounds of oil/acre yearly.

Table 9 shows some of the changes in land use that could occur if the programs suggested for the various commodities were implemented.

CONSTRAINTS TO AGRICULTURAL PRODUCTION

Land Improvements

Large acreages of mechanizable lands are producing far below their capabilities due to a lack of improvements such as efficient drainage and irrigation systems. Approximately 60,000 acres in the humid coastal valleys require efficient drainage systems and flood control measures such as channeling of rivers, construction of dams for flood control, and programs for reducing erosion in the watersheds.

About 40,000 acres in the semiarid region produce below their potential due to obsolete irrigation systems and an additional 20,000 acres could be irrigated if efficient systems were used including drip irrigation for vegetables and fruits and proper management of the wells and reservoirs. In addition, 30,000 acres in the humid region could be irrigated for rice production using now almost completely wasted river water.

All mechanizable lands should also be leveled or at least smoothed to facilitate drainage, irrigation and mechanization and some roads relocated to conform with the improved drainage and irrigation systems.

These land improvements are expensive and must be established in entire physiographic areas affecting a number of farms. Cost of these improvements, which must generally be financed by the Government, is estimated at $160 million to establish modern irrigation and drainage systems on 90,000 acres and efficient drainage systems on another 60,000 acres.

The Soil Conservation Service should concentrate its technical assistance on construction of ponds and drainage and irrigation systems and on land leveling. Financing of these improvements could be helped by assigning a given proportion of food stamp funds for this purpose and exempting 936 corporation funds from Federal taxes if invested in low interest loans to the Puerto Rico government for making such improvements.

Land Tenure

The following tabulation shows the number and area of farms by size according to the U.S. Census.

Area (acres)	Number of farms	Area (acres)
Less than 3	2,780	4,200
3 - 20	17,620	144,600
20 - 50	5,290	157,900
50 - 100	1,790	121,600
100 - 200	980	124,600
More than 200	1,380	706,800
Total	29,840	1,259,700

Land reform has long been a matter of great importance throughout Central America. In Puerto Rico, the "Land Law" passed in the 1940's attempted land reform in three areas: 1. relocating squatters on small plots where they could build their homes and have a small garden, 2. establishment of family size farms (usually 15 to 25 acres), and 3. large "Proportional benefit" farms expropriated from large sugar holdings and run by the Land Authority with workers sharing in the profits.

The program for relocating squatters was successful with 60,000 families now owning their plot of land, altho most have been subdivided among descendants of the original owners and have several homes.

The family-size farms have generally been a failure. Economic and sociological studies (Calero et al., 1974, Muler and Santini, 1976, and González-Villafañe et al., 1972) have shown that the farms are rarely profitable and many have been subdivided or sold. Failure is attributed to their limited size, very steep, unproductive soils, lack of credit and of entreprenurial abilities and little technical assistance in both production and marketing. In reality, there is little place in modern Puerto Rico, where people have high aspirations, for farms where a family subsists on a meager income obtained at great personal sacrifice.

The "proportional benefit" farms were run inefficiently, rarely produced profits for distribution among the laborers, and accummulated heavy losses. Most of these lands are now leased to private farmers for sugarcane and rice production.

On the other hand, farms where the owner, his family, and a limited number of laborers do the work should be fostered. Income from such farms should be sufficient ($10,000 or more annually) to attract people with the ability to become efficient farmers. Part-time farming should also be encouraged as a means of increasing income in rural areas. Home gardens could help increase food production in rural areas but the small size of lots in urban areas limits their potential for food production.

Availability of Land

A major obstacle to increased agricultural production is availability of land. Large areas are abandoned or under-utilized because their owners cannot, or do not need or wish to farm them. Many farms are not for sale or are offered at such high prices that young people with the ability and desire to become modern farmers cannot purchase them.

It is essential that agricultural lands be made available to people capable of farming them efficiently to increase local food production. Possible measures are: 1. zoning lands exclusively for agricultural use. This is difficult to implement and can involve considerable injustice which can be attenuated by a system for transferring part of the increased value of lands zoned for development to lands zoned for agriculture. 2. Increasing present very low land taxes while exempting those lands used efficiently for agriculture. 3. Substantial Government payments to farmers in exchange for an obligation to retain the land in agricultural production for a prolonged period. 4. Continue to rent Government owned land (About 110,000 acres, mostly agricultural) to farmers; and 5. Expropriate or rent lands from land owners and then sublet them to farmers for agricultural uses.

Human Resources

Human resources are a decisive factor in developing a modern agriculture. Laborers with special skills, farmers with entreprenurial abilities and a knowledge of modern technology, technicians trained in the basic sciences combined with practical experience, and a strong agricultural leadership with a sense of mission are indispensable. There are sufficient professional to develop a modern agriculture, with approximately 1,500 college-trained specialists in various fields, (800 employed by the Government) 200 with Master's degrees and 80 with Doctorates.

However, young, well-trained motivated farmers are scarce, probably as a result of the way agriculture developed on the Island. On the one hand, sugarcane, coffee and cattle developed on plantations based on cheap labor with the land holder delegating his responsibilities to poorly trained managers. As the Island's economy boomed, land holders became land-rich and many preferred to speculate with their lands rather than learn new techniques and make investments in agriculture. In addition, their off-spring generally entered professions other than agriculture. On the other hand, the off-spring of subsistence farmers who produced their own food, with a small patch of tobacco to provide cash, went to work elsewhere or migrated to the United States.

The social status of agricultural workers is also important. Agricultural work is considered of low status, partly as a result of the plantation or subsistence systems of farming discussed above, the higher wages paid in manufacturing, tourism and construction and the fact that farm owners often remain remote from their laborers who are under the supervision of a foreman incapable of dealing effectively with people. Contrary to popular belief, food stamps and other government social programs have not appreciably affected the availability of farm labor. Whereas formerly laborers worked in order to subsist, to a considerable extent many now work in order to maintain a standard of living in accordance with their higher aspirations. On the other hand, modern agriculture requires knowledge of machinery and technology and special skills and the farm owner often must work along with his laborers, all of which lend status to agricultural workers.

There is a need for training young, fairly well-educated people for agricultural pursuits. Although almost half of the Island's work force has a high school education, the 40,000 or so agricultural laborers on the average have only a 4th grade education and half are over 40 years of age. Average age of farmers is 55 years with a 5th grade education.

Despite unemployment rates exceeding 20%, farmers can find it difficult to obtain large numbers of part time laborers for such work as picking coffee or harvesting vegetables. On the other hand, there is a large pool of young, moderately well-educated persons willing to accept full time employment on farms where year-round employment is available at reasonable wages.

Agriculture can be an important source of employment but increased employment without at least a commensurate increase in production results variously in lower wages, higher prices, more government subsidies, losses to farmers or combinations of these. Enterprises that are naturally labor intensive such as coffee, bananas, vegetables, fruits and root crops should be encouraged but it is not likely than an efficient agriculture on the Island can employ much more than about 50,000 persons at reasonable salaries, with attractive profits for the farmers and fair prices for consumers. On the other hand, every job in agriculture creates at least another job in the Island's economy, considerably more than do industry or construction.

Local farmers, like those on the Mainland, must make payments for unemployment compensation, Social Security, and the State Insurance Fund. In addition, local laws require double wages for work in excess of 8 hours daily or 40 hours weekly, and paid annual vacations and there is no migrant labor available. On the other hand, the Government of Puerto Rico reimburses farmers $4.80 for every man-day of labor provided on their farms.

Federal minimum wages must be paid in all farm operations with more than 4,000 man-hours of labor/quarter (piece work such as harvesting coffee is not included) provided that either gross annual income exceeds $250,000 or the produce enters interstate commerce. These requirements can severely affect farmers with non mechanizable operations. Whereas large mechanized farms in the United States, and on the coastal areas of Puerto Rico as well, can be operated with only a few laborers, those in the mountain region are by necessity labor intensive. For example, farms with only 60 acres of intensively managed coffee, bananas or plantains require about 5,000 man-hours/quarter and therefore must pay minimum federal wages.

It must be borne in mind that it is possible to live fairly well on low wages in many rural areas since most families live in debt-free homes built over a number of years with the help of relatives and neighbors, payments for electricity and water are low, there is no need for heat or cooling since the climate is benign, extended families pool their incomes, schooling as well as health care are free and food stamps are available.

The College of Agricultural Sciences and the local Department of Education should establish cooperative programs to train young people as technicians and farm managers.

The Federal government could raise the limit for exemption of payment of minimum federal wages for non mechanizable agricultural operations in the mountain region from 4,000 to 6,000 man-hours per trimester. It could also assign a specific proportion of the food stamp funds (PAN) and/or, any increases in these funds, to increase employment and local food production. Increased income to laborers could reduce payments for food stamps and for unemployment compensation and reduce migration to the Mainland.

Technology and Technology Transfer

Agriculture in Puerto Rico must be based on the most modern technoloy available in order to reduce costs and be able to compete on the one hand with imports from the United States where agricultural production is very efficient, and on the other, with those from tropical countries where land and labor are cheap. However, technology must be appropriate to local conditions; direct transfer from other countries can be disastrous.

The College of Agricultural Sciences of the University of Puerto Rico at Mayaguez is a Land-Grant institution. The Faculty grants Bachellor degrees in most fields of agriculture and Master degrees in many. The Experiment Station develops technological packages of practices for efficient crops and livestock production and the Extension Service is responsible for transferring this technology to the farmers.

There is locally tested technology for the efficient production of most crops grown on the Island, or with a potential for local production, but much of this technology is not being put to use by local farmers. The traditional system used by Extension to transfer technology following the U.S. pattern (written material, lectures, meetings and TV and radio programs) has not been effective, which is not surprising considering that the average farmer is 55 years old and has a 5th grade education.

Most farmers can only be convinced of the benefits of modern technology if they see it practiced on a neighboring farm. The following system for technological transfer in Puerto Rico has been proposed (Anonymous, 1982). The latest technological packages for the various crops are first tested on Experimental Farms. Failures (paid for by the Government) help focus research on problems of real importance.

If successful, the technological packages are transferred to Demonstration Farms located in the areas best suited to the production of the various crops. Farmers are taken to these farms and their technical and economic aspects explained to them, preferably by the farm owner himself. Entreprenurial Farms, those having a potential for becoming modern operations, are identified and selected Extension Agents assigned to work exclusively with small groups of these farmers helping them to apply modern technology. Other Extension Agents, suited by training and attitude to help Traditional Farmers, will continue to do so and engage in other Extension Service activities such as 4-H Clubs.

The Federal and local governments should increase funds for Research and Extension,which have not kept pace with inflation, and target them to specific crops and problems, with applicability to large areas in the Caribbean Basin.

Agricultural Credit

The Federal Land Bank, the Production Credit Administration and the Farmers' Home Administration offer their traditional forms of credit in Puerto Rico. The Agricultural Credit Corporation of the Puerto Rico Department of Agriculture makes a large number of loans, mostly to small farmers, and guarantees some agricultural loans made by commercial banks. Private banks, however, make few agricultural loans. Approximate agricultural loans are as follows: Federal Land Bank, $80 million, Production Credit Association, $25 million, Farmers' Home Administration, $30 million, Agricultural Credit Corporation, $25 million, and private banks, $20 million. In addition, the Sugar Corporation owes about $500 million guaranteed by the Government Development Bank.

It is estimated that agricultural credit must be expanded fourfold in order to meet the needs of a modern agriculture. The lack of sufficient volume makes it difficult for private banks to develop a unit with the expertise and experience necessary to make agricultural loans.

The local government could help increase available credit by exempting agricultural loans from the franchise tax paid by private banks or by subsidizing entities capable of providing technical assistance to banks until a sufficient volume of business develops. It could also help clear titles which are not clear in many farms making it difficult to use them as collateral.

The Federal government could exempt 936 Corporations funds from federal taxes while they are invested in agricultural loans at moderate interest rates and mandate that a fixed,relatively high proportion of FHA funds be used to finance agricultural projects to increase local food production.

Marketing

The local market is stable but is relatively small for most commodities and even small surpluses can sharply depress prices since they cannot be readily shipped to distant Mainland markets which are exacting as to supply and quality of produce. On the other hand, the local market is "protected" by the high cost of transporting imported products (about 2.5¢/pound for grain and 6-7¢/pound for refrigerated products) and can be regulated in various ways.

It is difficult to supply the local market with quality products on a year-round basis since many factors in agricultural production cannot be controlled and it is difficult to adjust production to demand on a short-term basis. Also, local marketing systems for fresh produce are generally inefficient, grading is not uniform, packaging is often primitive, handling is careless and storage facilities are limited.

Many products are sold on the farm and competition between buyers has improved the bargaining position of farmers. Products such as bananas, oranges, tomatoes and peppers, are also sold at relatively low prices at stop signs, main intersections, and in shacks along the main highways near the larger cities. Prices at rural markets, however, are usually rather high since buyers are often touring the countryside for recreation and purchase produce as a present for friends or relatives with price a minor consideration compared to novelty, freshness and appearance of the produce.

Retail prices for most locally produced commodities remain high. Middle men and retailers benefit from these high, stable prices but make farmers subject to the fluctuations of supply and demand. Margins for marketing are generally lower than those on the Mainland since there is less packaging and handling and distance from farms to market are shorter.

There are several large processors of agricultural products but, with the exception of pineapples and pigeon peas, they depend almost exclusively on imported materials and are not interested in processing small periodic agricultural surpluses. There are also several small processors of such products as candied fruits and jellies.

The Island's agriculture can be oriented towards supplying the local market which is in a sense protected by high shipping costs.

The local market can be fully supplied with coffee, plantains, bananas, pigeon peas, sugar, root crops, milk, citrus, pineapples and other tropical fruits, wood, and some vegetables. A majority of the rice, pigs and poultry products could also be produced locally altho the latter two would be based largely on imported feed since grain production requires large acreages, provides a low income and little employment, and is faced with strong competition from imports.

If export oriented, tens of thousands of acres could be planted to such high income, labor intensive crops as pineapples, vegetables, bananas, mangos and other fruits, and also possibly coffee and cocoa. With the exception of vegetables, none of these products are produced on the U.S. Mainland but most face stiff competition and wide price fluctuations on the world market.

The logical alternative is to produce as much as possible for the local market, with suitable safe guards to prevent an over supply of perishable products on the one hand,and a steady supply of good quality products on the other, and to produce for export only those commodities which can be produced in competition with other areas.

The removal of U.S. tariffs on produce from Caribbean Basin countries as a result of the Caribbean Basin Initiative, will probably have only minor effects on agricultural production for the local market. The tariffs range from 1-3¢ per pound for produce retailing locally at prices often 20 times higher and the exporting in countries have always had the huge advantage of agricultural wages ranging from $2-4 daily compared to $16-26 in Puerto Rico, depending on whether the farm pays federal minimum wages. The reduction in tariffs, however, could have considerable effect on the export market for Puerto Rican fresh produce.

The local government could help improve marketing by establishing quality standards for local produce, providing incentives to entities marketing local produce on the Mainland or other export markets and help to finance new local marketing facilities. The Federal government might consider establishing a mechanism for effectively implementing federal anti-dumping legislation whenever Mainland products are sold in Puerto Rico at prices below the cost of production.

Materials and Services

A lack of equipment, materials and services of the kind and quality needed and at the required place and time adversely affects agricultural development.

The Puerto Rico Department of Agriculture provides equipment to farmers at subsidized prices for the construction of farm roads and for clearing and plowing land. It also sprays coffee, plantain and banana plantations for low fees and operates stores offering livestock feed, fertilizer and a wide range of agricultural products in small towns. However, these services are often deficient due to a lack of funds and an often inefficient burocracy.

The local government should provide needed supplies, services and equipment only where private entities cannot do so and the latter should be granted incentives if necessary to provide these services as required.

Government Action and Incentives

Intervention by Government in agricultural development is inevitable, especially on a small island with limited resources and a history of massive government influence, and complicates agricultural development by introducing an inefficient burocracy as well as politics into an already difficult situation.

Bonafide farmers are granted 90% exemption from local income taxes. Land taxes are low and those used for intensive agricultural production are exempt. Land is also exempt from inheritance taxes if used for agriculture. There are also many complex incentive programs for agriculture but these are expensive to administer, change constantly, occupy much of the time of farmers and technicians and with few exceptions, have little effect in increasing agricultural production or efficiency. Traditional farmers should continue to receive assistance but this should not be of a type or magnitude as to indefinitely prolong inefficient production.

Incentive programs aimed at modernizing agricultural production should meet the following criteria (Vicente-Chandler, 1978): 1. Expensive permanent improvements to infrastructure; 2. enterprises or practices whose financial benefits are only obtained over a long period of time; 3. new, improved techniques for more efficient production which, once accepted, will be carried out without further incentives; 4. technology which increases conservation and utilization of natural resources rather than use of imported materials; 5. incentives should be paid only when the entire technological package is applied and should be combined with technical assistance and the necessary credit.

Special attention should be paid to commodities or technologies that are labor intensive and fully utilize the Islands' resources. Table 8 shows that vegetables, pineapples, starchy vegetables, coffee, citrus, plantains and bananas are labor intensive and require relatively little imported materials. On the other hand, eggs, poultry and pigs, require little labor and are based on imported feeds which account for about 70% of production costs.

In addition to actions suggested with regard to the various commodities, the following initiatives should be considered: 1. Change the current system for registering pesticides,which requires local registration, costly to manufacturers compared to the potential local market, so that those approved for Southern United States can also be used for the same crops in Puerto Rico. 2. Increase support for an expanded program of winter nurseries. The productivity of Mainland breeding programs for rice, sorghum, corn, wheat, oats, soybeans and others could be doubled by producing an additional generation during the winter months in Puerto Rico. 3. Support development of long-term plans and programs for increasing food production which, if accepted by federal and state agencies, could help to make better use of funds and efforts. Agencies which could be involved in planning, and later in implementation are US-ACP, SCS, FHA, ARS and FS and Puerto Rico-Experiment Station, Extension Service, Department of Agriculture, Planning Board and Economic Development Administration. 4. The current ARS program for maintaining germplasm of tropical crops, which cannot be propagated from seed or whose seed cannot be stored for prolonged periods, should be expanded to serve the Caribbean Basin and much of the Tropics and include bananas, plantains, cacao, mangos, avocados, oil palm and tropical root crops, among others.

ASSESSMENTS OF AGRICULTURAL PRODUCTION TECHNOLOGIES FOR U.S. CARIBBEAN ISLANDS - U.S. VIRGIN ISLANDS

INTRODUCTION

The U.S. Virgin Islands, St. Croix, St. John and St. Thomas, are located about 50 miles Southeast of Puerto Rico. Their total area is 136 square miles (84,400 acres) with a population of about 115,000. St. Croix is 84 miles square with a population of about 60,000, St. Thomas is 32 miles square with a population of about 50,000 and St. John is 20 miles square with a population of about 5,000.

Whereas agriculture was the mainstay of the economy of St. Croix, it now plays only a very minor role. Production of sugarcane, formerly the main crop, declined rapidly and after suffering heavy losses was discontinued in 1965.

The main industry of the Virgin Islands is tourism with 1.2 million visitors spending $100 million yearly. The two largest manufacturers are Hess Oil Company producing about 700,000 barrels a day and Martin Marietta Aluminum, which employs about 450 persons. About 2 million gallons of rum are produced yearly with federal taxes returned to the Virgin Islands's Government.

The Islands have a good road system and excellent communications with the United States. About 25,000 students are enrolled in the schools and about 2,000 study in the College of the Virgin Islands.

WATER RESOURCES

At a typical location in St. Croix average daily maximum temperatures varied from 83 to 89°F and minimums from 70 to 76°F and average relative humidity ranged from 81 to 90% at 2:30 AM and from 63 to 73% at 2:30 PM (Table 10). Monthly precipitation data show a dry season from about January through April and highest rainfall from August to November with a total of about 45 inches yearly. Potential evapotranspiration far exceeds rainfall during all but the 3 months of heaviest rainfall indicating a moisture deficit during most of the year (Table 10). Rainfall in the Virgin Islands increases with elevation from 20 to 30 inches at the lower elevations to 50 to 60 inches at the higher ones.

The Islands have no large rivers or large reservoirs. St. John and St. Thomas have no subterranean water and those of St. Croix are very limited with several wells capable of producing a total of only about 250,000 gallons daily. In St. Thomas and St. John rain water from catchments is supplemented by potable water barged in from Puerto Rico and water from 3 sea water distillation plants which can produce 3.75 mgd. One plant in St. Croix can produce 1 mgd.

About 220 small ponds have been constructed in St. Croix, mostly on cattle farms. Assuming that an additional equal number could be constructed and hold an average of 8 acre-feet each, all together could provide enough water to irrigate about 1,000 acres.

It is obvious that lack of water is the main physical factor limiting agricultural production in the Virgin Islands.

SOIL RESOURCES

The following tabulation shows the area of the major soil groups of the Virgin Islands:

1. Descalabrado-Jácana	Strongly sloping to steep, shallow to moderately deep	16,000 acres
2. Aguilita-Fredensborg-Sion	Gently sloping to steep, shallow	18,600 "
3. Cramer-Isaac	Very steep to strongly sloping, shallow to deep	34,500 "
4. Dorothea-Victory-Magens	Steep to very steep, deep	1,700 "
5. Southgate-Parasol	Steep to sloping, shallow to deep	1,700
6. Fraternidad-Aguirre-Glynn	Nearly level to moderately sloping, well drained to poorly drained, deep	6,800
7. Cornhill-Coamo-San Antón	Nearly level to moderately sloping, moderately to well drained, deep	5,100
	Total	84,400

Almost all the land in St. Thomas and St. John is in Groups 3 and 4 (very steep to strongly sloping and shallow to deep), not generally suited to agriculture except for fruit trees on the deeper soils and small vegetable gardens in terraced fields.

In St. Croix, about 12,000 acres in Groups 6 and 7 are well suited to agriculture and an additional, larger area, is suited to pastures. However, lack of moisture seriously limits agricultural production even on the best soils.

There are about 330 farms with a total of 24,700 acres and only 35 are larger than 100 acres.

AGRICULTURAL COMMODITIES

Milk

St. Croix and St. Thomas are about self-sufficient in milk production. Approximately 2 million liters of milk are produced yearly in St. Croix and 1.7 million on St. Thomas and 400,000 are imported (Table 11).

Milk is the main agricultural industry of the Islands and continues to expand (Dhillon and Park, 1974) protected by the cost of importing fresh milk. However, considerable competition could develop from UHT milk from Puerto Rico and the U.S. Mainland. There are 8 commercial dairies in the Virgin Islands with about 900 milk cows on 5,000 acres of improved pastures.

Milk production should be based as much as possible on intensively managed and fertilized pastures of Guinea or Buffel grasses with higher yielding cows fed limited quantities of expensive concentrates, all of which are imported. About 2,000 tons of mixed livestock feeds are imported yearly from Puerto Rico, mostly for dairies. Grazing must be complemented by feeding silage during the dry season. With proper care, Buffel and Guinea grass can be made into hay or fairly good silage, but sorghum silage has a higher nutritive value. Sordan (sorghum x sudan grass) can yield 60 tons of green forage/acre yearly (Ott et al., 1974) and several forage sorghum hybrids can yield over 40 tons.

Grain sorghum can also produce a seed and a ratoon crop with total yields of 4-5,000 pounds/acre (Conje, 1978). This crop could be grown on 12,000 acres of excellent soils in St. Croix. However, there is little machinery available for producing, harvesting and drying the grain and most farmers with managerial talents are not inclined to make the required heavy investments.

Beef

About 860,000 pounds of beef and veal are produced yearly in the Virgin Islands and 4,260,000 are imported (Table 11). There are about 5,000 head of beef cattle on 8,000 acres of improved pastures (Park and Park, 1974) and about 12,000 acres of unimproved grasslands.

Some land owners use beef production to reduce the cost of holding land pending conversion to higher economic uses. Returns can cover out-of-pocket costs and give a return to management but cannot pay for investment in the land (Park and Park, 1974).

Production is mostly of medium quality beef animals for relatively low income consumers. The locally developed breed - Senepol - (Hupp, 1978) is very well adapted to conditions on St. Croix and can produce fair quality beef from grass alone. The tourism industry relies mostly on imported high quality beef.

Pigs, Poultry and Goats

About 160,000 pounds of pork are produced yearly and 1,840,000 are imported, 10,000 pounds of poultry are produced and 9,100,000 are imported, 140,000 dozen eggs are produced and 1,430,000 are imported, and 20,000 pounds of goat and lamb meat are produced and 590,000 are imported (Table 11). There is therefore a large market for locally produced pigs, poultry, goats and lambs, if they can be raised economically (Stammer, 1974).

There are approximately 1,000 hogs and a strong demand for 40-50 pound pigs for roasting especially near Christmas with some demand for 120-pound animals throughout the year (Jensen and Park, 1974).

The main limitation to increased pig and poultry production is the high cost of concentrates, all of which are imported, competition from imported products from the U.S. Mainland, little experience in scientific production methods, and a lack of modern marketing facilities. Since these products are based on imported feed, which accounts for more than 2/3 of production costs, and are not labor intensive if modern techniques are used, they would make only a limited contribution to the economy of the Virgin Islands. The potential for increased goat and sheep production fed on local forage is much better (Park and Park, 1974).

Fruits and Vegetables

Consumption, production and imports of the main fruits and vegetables are shown in Table 11. About 95% are imported.

Vegetable production on small plots for home use offers possibilities where some water can be obtained from catchment areas or small wells. Mangos, avocados, citrus and bananas can also be grown successfully on small plots near homes.

Production on anything approaching a commercial scale must be based on water stored in ponds. The best season for vegetable production is during winter, precisely when rainfall is scarcest. As noted previously, maximum amount of land which could be irrigated is about 1,000 acres but more realistically nearer to 500. Table 12 shows the acreage which would have to be planted to the main fruits and vegetables in order to meet local demand. A total of about 343 acres would be required but only 196 acres would be needed if production were limited to the period of best production (Mullins and Bohall, 1974).

Mangos, papayas, citrus, plantains, bananas and other tropical fruits can be grown without irrigation in areas with deep soils and fairly high rainfall, but yields will be adversely affected during dry years, particularly since the drier months coincide with the period when many fruits are developing.

Pigeon peas can be planted and produce high yields during the rainy period which coincides with their bearing season.

Woodland

Although about 30,000 acres are in woodlands, there is no commercial forestry and little prospects for such an industry to develop in the future (Somberg, 1976). There are approximately 500,000 board feet of commercial mahogany on the Island mostly on about 300 acres in central St. Croix and small plantings of mahogany continue to be made.

Mariculture

A good potential exists for mariculture in shallow areas and reefs. Technology developed in Hawaii could be transferred and, when necessary, adapted to conditions in the Virgin Islands.

CONSTRAINTS TO AGRICULTURAL PRODUCTION

The prospects for increased agricultural production in the Virgin Islands other than for meat and milk appear bleak. The limited amount of land suited to agriculture, the lack of rainfall and water for irrigation, the high cost of land, the lack of interest in agriculture by persons with managerial abilities, the expensive and unproductive labor, the small and relatively inflexible local market and the strong competition from high quality imports available throughout the year, (although expensive) are major disincentives.

Although agriculture was the mainstay of the economy of St. Croix, it is currently of low status, probably as a result of slavery. As a result, there is a scarcity of agricultural labor, and that which is available is expensive and unproductive. In the past, laborers were imported from Puerto Rico and there has been considerable pressure for importing laborers from neighboring islands. This problem can be attenuated by use of modern technology and mechanization and by increasing wages with supplementary payments by the local government as done in Puerto Rico.

Quite a few of the farmers, especially those producing fruits and vegetables, work part-time, many for personal satisfaction and for their own consumption.

It is theoretically possible to supply the local market for fresh fruits and vegetables from lands that might be irrigated following a massive program of pond construction although other constraints will probably make this impossible.

Another obstacle to increased agricultural production is the high price of land due to speculation and the heavy demand for home sites by local people and retired persons or those interested in winter homes. It is impossible to pay for the land from agricultural enterprises except the most intensive irrigated truck farming. Possibilities for ameliorating this problem are discussed in the report on Puerto Rico.

Local farmers, like those on the U.S. Mainland, must make payments for unemployment compensation, Social Security and state insurance funds. Federal minimum wages must be paid by all enterprises with more than 4,000 man-hours of labor per trimester and which, additionally, have an income above $250,000 yearly or produce that enters interstate commerce.

The Virgin Islands have a Land-Grant College comprising teaching, research and extension in agriculture. Current efforts would seem to be sufficient in view of the limited agricultural potential of the Islands. Systems for technology transfer like those recommended for Puerto Rico could be effective.

The Federal Land Bank, Production Credit Association and Farmers' Home Administration offer their traditional forms of credit but there is little demand for agricultural loans. If these should increase, private banks could participate in providing credit for agriculture.

Imports offer almost insurmountable competition since they are available in large quantities throughout the year and are of excellent quality although expensive.

Agricultural production should be limited to the local market where food is expensive. Residents are by far the main consumers. The tourist market is small, requires high quality and is mostly supplied by imports from the U.S. Mainland.

Marketing systems must be improved but should remain simple altho with better quality control. There are two regional chain stores, severa intermediate size ones, numerous neighborhood stores served by two local wholesalers, and a number of roadside markets plus farmers' markets during some days of the week. Three large purveyors provide most of the restaurants and hotels.

Local production should be aimed, at least initially, at home consumption and sale at roadside and farmers' markets and in neighborhood stores where careful packaging, etc., are not very important.

The main efforts by Government, both local and Federal, should be to help in the increased construction of farm ponds for irrigation by providing technical assistance, machinery and subsidies.

Continued technical assistance, based largely on the transfer of technology from areas with similar climate and soils on the south coast of Puerto Rico, should be increased.

There is also a need for the materials, machinery and services required by a high technology agriculture. These should be provided by the Government only where they cannot be provided by the private sector.

In addition, funds could be assigned to increase plant introductions and evaluations in the Virgin Islands with crops not grown there but of interest to the United States and which cannot be introduced directly to the Mainland due to quarantine restrictions.

Table 1.--Changes in agricultural production during the past 30 years and present (1982) local production, imports and consumption 1/

Commodity	Production 1951-52	Production 1981-82	Consumption 1/ 1981-82	Imports
Sugar (tons)	1,360,000	103,000	140,000	37,000
Tobacco (q.)	281,000	16,000	--	--
Coffee (q.)	237,000	250,000	390,000	140,000
Fresh milk (lts.)	45,700,000	374,000,000	380,000,000	6,000,000 (UHT) 2/
Beef (lbs.)	24,700,000	38,000,000	114,000,000	76,000,000 3/
Pork (lbs.)	18,800,000	40,000,000	113,000,000	73,000,000 4/
Poultry (lbs.)	12,600,000	52,500,000	195,000,000	142,000,000
Eggs (doz.)	9,500,000	21,900,000	39,400,000	17,500,000
Pineapple (tons.)	22,000	42,000	3,000	--
Plantains (thousands)	170,000	330,000	330,000	--
Bananas (thousands)	1,120,000	720,000	720,000	--
Tanier (q)	432,000	240,000	415,000	175,000
Sweet potatoes (q.)	280,000	210,000	320,000	100,000
Yams (q.)	256,000	321,000	321,000	1,300
Oranges (thousands)	144,000	162,000	192,000	31,000 5/
Grapefruit (thousands)	16,000	6,600	8,600	2,000
Citron (q.)	73,000	89,000	--	--
Pumpkins (q.)	182,000	457,000	457,000	--
Tomatoes (q.)	179,000	68,000	353,000	285,000
Pepper (q.)	79,000	80,000	137,000	60,000
Cabbage (q.)	66,000	80,000	170,000	106,000
Pigeon peas (q.)	116,000	110,000	125,000	15,000
Taro (q.)	115,000	75,000	75,000	--
Cassava (q.)	130,000	60,000	85,000	25,000
Potatoes (q.)	--	--	1,323,000	1,323,000
Rice (q.)	--	100,000	3,100,000	3,000,000
Beans (q.)	--	8,000	440,000	430,000
Onions (q.)	--	--	357,000	370,000
Corn (q.)	--	--	4,500,000	4,500,000
Grapes (lbs.)	--	--	5,100,000	5,100,000
Garlic (lbs.)	--	--	3,600,000	3,600,000
Cocoa (lbs.)	--	--	--	10,000,000 6/

1/ Exports from Puerto Rico to Virgin Islands and to others account for some of the discrepancies between imports, local production and consumption.

2/ The equivalent of about 150,000,000 liters are imported in dry or condensed form.

3/ 28,000,000 pounds from USA and 48,000,000 pounds from foreign countries.

4/ + 28,000,000 pounds of ham.

5/ + 4,000,000 gallons of concentrate.

6/ + 15,000,000 pounds of chocolate candies.

Table 2.--Per acre yields for various agricultural enterprises obtained at present, compared to those with modern technology

Agricultural Enterprise	Unit	Present	Modern Technology	% Increase
Coffee	Cwt.	1.8	15.0	833
Plantains	No.	22,000	35,000	160
Starchy Vegetables	Cwt.	60	200	330
Pigeonpeas	Cwt.	6.0	20	333
Sugarcane	Ton.	2.5	4.0	160
Rice 1/	Cwt.	--	100	--
Pineapples	Ton.	11	20	182
Hay	Ton.	5.0	12.0	240
Tomatoes	Cwt.	100	300	300
Peppers	Cwt.	100	250	250
Cabbage	Cwt.	100	250	250
Pumpkin	Cwt.	120	200	167
Bananas	Cwt.	200	400	200
Citrus	No.	20,000	60,000	300

Table 3 - Area and production of different agricultural commodities which could provide all the nutrients required by Puerto Rico's current population.

Commodity	Mechanizable lands	Partially mechanizable lands	Annual dry matter production	
			Carbohydrates	Protein
	(acres)	(acres)	(millions of hundredweight)	(hundredweight)
Rice	50,000	--	3.1	200,000
Bananas	10,000	10,000	2.0	50,000
Plantains	--	80,000	7.8	200,000
Sugarcane	40,000	--	2.6	--
Root crops	20,000	--	0.6	20,000
Soybean	20,000	--	0.6	300,000
Milk	50,000	250,000	0.3	300,000
Beef	--	100,000	0.1	120,000
Vegetables	20,000	--	1.2	50,000
Fruits	--	20,000	0.2	20,000
Coffee	--	30,000	--	--
Beans and Pigeon peas	20,000	--	0.3	100,000
African Oil Palm	--	20,000	1.4	--
Grains for pigs and poultry	40,000	--	0.6	400,000
Total	270,000	510,000	20.8	1,760,000

1/ Based on 2,500 calories and 2 ounces of protein daily/person, 3.3 million persons require 1.5 million hundred-weights of protein and 20.5 million hundredweight of carbohydrates yearly.

Table 4. - Basic data on some of the reservoirs in Puerto Rico 1/

Name of lake	Name of river	Watershed (acres)	Storage capacity in 1975 (acre-feet)
Guajataca A1/	Guajataca	15,744	29,300
Matrullas R	Arecibo	2,816	2,620
Guineo R	Arecibo	1,024	1,710
Garzas A	Arecibo	3,968	4,300
Carite R	Guamaní	5,056	10,700
Comerío -	La Plata	87,000	--
Dos Bocas -	Arecibo	108,800	16,800
Caonillas -	Arecibo	32,256	43,000
Luchetti R	Yauco	11,072	15,600
Prieto R	Añasco	6,144	300
Guayo R	Añasco	6,144	16,900
Yahuecas R	Añasco	11,136	1,670
Patillas R	Patillas	16,128	14,400
Guayabal R	Jacaguas	27,520	6,300
Loco R	Loco	5,376	1,500
Loíza A	Loíza	131,840	12,700
Cidra A	Bayamón	5,500	3,800
Las Curías A	Puerto Nuevo	700	--
La Plata A	La Plata	110,720	21,700
Toa Vaca A	Toa Vaca	14,080	50,660
Total			253,960

1/ A for aqueduct
R for irrigation + hidroelectric
- only for hidroelectric

Table 5.--Some possible new reservoirs

River	Watershed (sq. miles)	Yield (mgd)	Storage Capacity (acre feet)
Cibuco	14.2	13.6	16,090
Manatí	127.3	100.0	94,410
Añasco	126.9	173.0	162,850
Loíza	16.5	12.2	23,040
Salinas	19.1	23.6	22,750
Coamo	11.7	16.1	15,500
Guayanilla	18.6	16.1	17,000
Cayaguas	6.0	16.1	14,860
Fajardo	15.2	13.2	3,000
Guayanés	4.5	13.7	13,420
Yaguez	6.1	11.9	9,100
Guanajibo	17.7	27.9	11,900
Culebrinas	60.7	84.4	32,530
Total			436,450

Table 6.--Minimum flow (exceeded during 90% of the year) for some of the major rivers of Puerto Rico

River	Minimum flow	
	m.g.d.	C.F.S.
	North Coast	
Guajataca	6.5	10
Camuy	26.0	40
Arecibo 1/	141.0	217
Manatí	65	100
Cibuco	17.6	27
	West Coast	
Guanajibo	18	28
Añasco	52	80
Culebrinas	31.2	48
	East Coast	
Grande	13	20
Espíritu Santo	13	20
Mameyes	15	23
Fajardo	13	20
Blanco	11.7	18
Humacao	5.2	8

1/ Before construction of Dos Bocas and Caonillas lakes (Figure 4) which can be used for irrigation.

Table 7 - Soil resources available for agriculture in Puerto Rico grouped in accordance with their agricultural potential

	Acres available
I. Soils of the humid coastal region	
A. Deep, alluvial soils (sugarcane, rice, bananas, grain)	103,300
B. Deep, red soils (pineapples, pigeon-peas, root crops, dairying)	94,500
II. Soils of the humid midlands	
C. Soils of rolling topography (plantains, citrus, bananas, root crops, dairying)	107,700
III. Soils of the humid mountain region	
D. Deep soils with < 50% slopes (coffee, plantains, bananas, citrus, dairying, beef cattle)	485,300
E. Medium deep soils with < 50% slopes (commercial forests)	280,500
F. Shallow soils or soils > 50% slopes (natural woodlands, wildlife, recreation)	227,600
G. Shallow calcareous soils (natural woodlands, wildlife, recreation)	81,400
IV. Soils of the semi-arid region	
H. Deep, level, heavy, irrigable soils (sugarcane, hay, grains, bananas)	47,200
I. Deep, level, friable, irrigable soils	24,200
J. Gently rolling soils, (some-adapted to drip irrigation) (mangos and other fruits)	39,300
K. Steep shallowsoils (natural woodlands, wildlife and recreation)	230,000
V. Soils of the coastal lowlands	
L. Saline, organic, marshy or sandy (aquaculture, ecological reserves)	96,500
Total	1,817,500

Table 8.--Approximate per acre or per unit yearly costs for labor, materials and others for various agricultural enterprises using modern technology

Agricultural enterprise	Labor 1/	Materials	Others 2/	Total
Sugarcane	180	203	502	885
Rice 3/	84	286	466	836
Vegetable Crops 3/	1,333	605	433	2,371
Pineapples	912	220	650	1,782
Pigeonpeas	135	129	152	416
Starchy vegetables	966	281	351	1,598
Hay	132	286	416	834
Dairy	180	430	650	1,260
Beef	90	248	180	518
Coffee	840	350	584	1,774 6/
Citrus	915	224	640	1,779 6/
Plantains	750	623	414	1,787
Bananas	1,250	901	479	2,630
Mangos	300	154	415	869
Eggs 4/	204	2,640	856	3,700
Poultry 5/	156	1,720	208	2,084
Pigs 5/	312	2,180	756	3,248

1/ At federal minimum wages.
2/ Includes State Insurance and Social Security payments, use of machinery and of land and others.
3/ 2 crops yearly.
4/ Per 4,000 dozens of eggs.
5/ Per 4,000 lbs. liveweight.
6/ Does not include cost of establishing plantations and bringing them into production.

Table 9. - Approximate proposed changes in land use for agricultural lands of Puerto Rico

Commodity	Mechanizable lands (270,000 Acres)		Partially Mechanizable Lands (600,000 Acres)	
	Present	Proposed	Present	Proposed
Sugar	60,000	40,000	10,000	--
Rice	2,500	36,000	--	--
Vegetables	2,500	15,000	3,000	--
Pineapples	4,000	12,000	--	--
Pigeon Peas	2,000	7,000	15,000	--
Milk	90,000	70,000	70,000	110,000
Beef	60,000	27,000	100,000	150,000
Hay	2,000	5,000	--	--
Coffee	--	--	100,000	50,000
Plantains	2,000	3,000	13,000	13,000
Bananas	--	10,000	8,000	7,000
Mangos	--	--	3,000	10,000
Citrus	--	--	12,000	7,000
Root Crops	1,000	1,000	10,000	8,000
Woodland	--	--	--	100,000[1/]
Small holdings, discontinuous areas, etc.	44,000	44,000		
Total	270,000	270,000	344,000	455,000

1/ Plus 200,000 acres on non-agricultural soils.

Table 10. - Monthly temperature, precipitation and evapotranspiration at Alexander Hamilton Field, St. Croix

Month	Temperature		Precipitation	Potential Evapotranspiration
	Average daily maximum	Average daily minimum		
	°F.	°F.	In.	In.
January	83	70	2.23	3.89
February	83	70	2.19	3.67
March	84	71	1.73	4.45
April	86	73	2.83	4.96
May	86	74	4.31	5.94
June	88	76	3.10	6.27
July	88	76	3.51	6.55
August	89	76	4.58	6.40
September	88	75	6.65	5.85
October	88	75	5.45	5.69
November	86	73	4.65	4.90
December	84	72	3.34	4.27
Year	86	73	44.57	62.78

1/ Based on Thornwaite's formula.

Table 11. - Imports, local production and consumption of fresh fruits, vegetables and livestock products in the Virgin Islands in 1972 (thousands of pounds except as noted

	Imports	Production	Consumption
Oranges	684	7	691
Grapefruit	219	3	222
Lemons and limes	43	5	48
Avocado	140	5	145
Bananas	857	100	957
Plantains	79	-	79
Mangos	30	56	86
Melons	760	-	760
Tomatoes	768	80	848
Onions	836	10	846
Cabbage	350	8	358
Potatoes	1,556	-	1,556
Dasheens	203	-	203
Beef and veal	4,260	860	5,120
Pork	1,840	160	2,000
Goat and lamb	590	20	610
Poultry	9,100	10	9,110
Eggs (thousand doz.)	1,430	140	1,570
Milk (thousand liters)	400	3,700	4,100

Table 12.--Acreage of selected fruits and vegetables required to meet Virgin Islands'[1] consumption requirements in 1980

Commodity	Consumption (thousand pounds)	Acreage	Acreage required during production periods
Tomatoes	1,287	91.9	46.0
Onions	1,269	68.2	45.5
Cucumber	289	49.8	24.9
Peppers	217	21.7	10.8
Okra	72	5.2	5.2
Lettuce	1,159	77.2	38.6
Pineapples	434	15.5	15.5
Papayas	145	6.6	6.6
Mangos	129	7.8	2.6
Total	5,000	343.9	195.7

---

[1] Divide by 1/2 to obtain approximate needs for St. Croix alone.

Figure 1. - Average rainfall in Puerto Rico (inches/year)

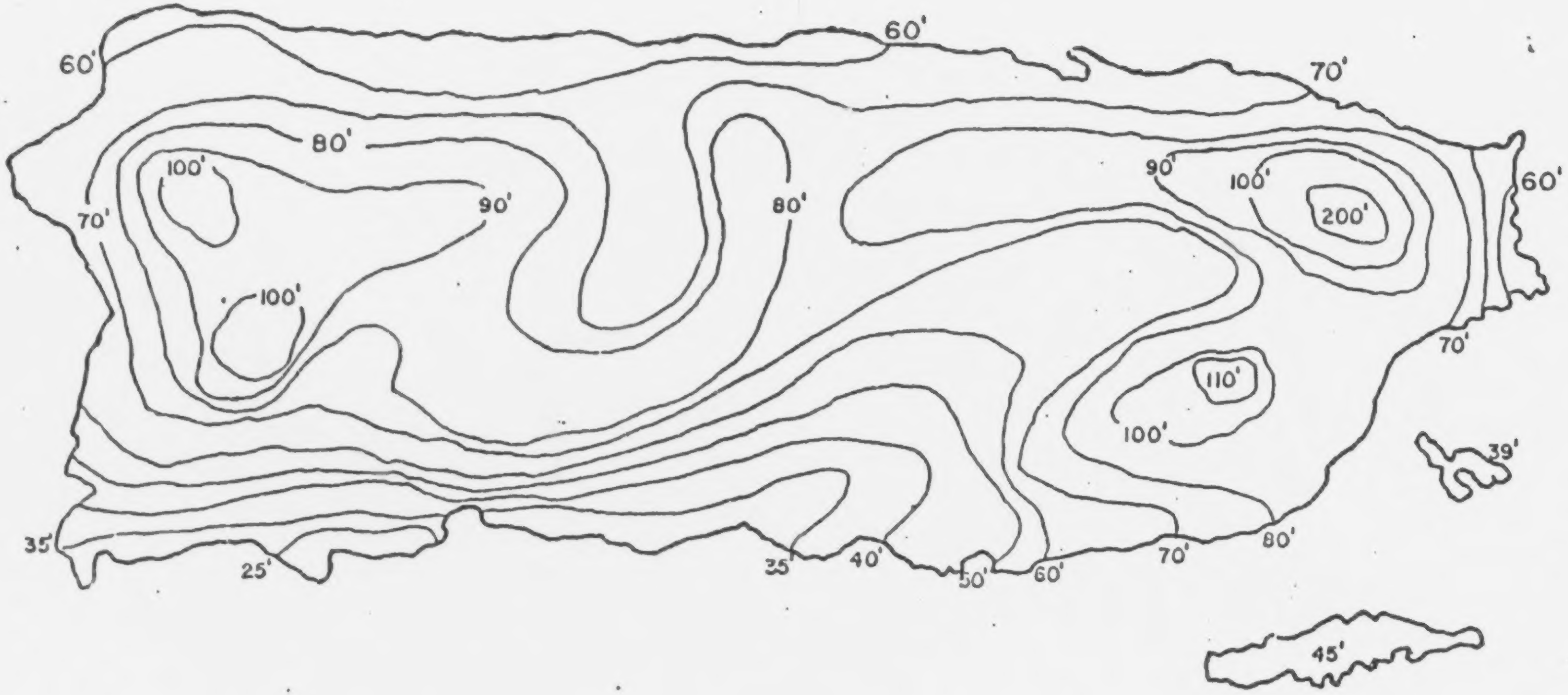


Figure 2. - Average evapotranspiration potential in Puerto Rico (inches/year)

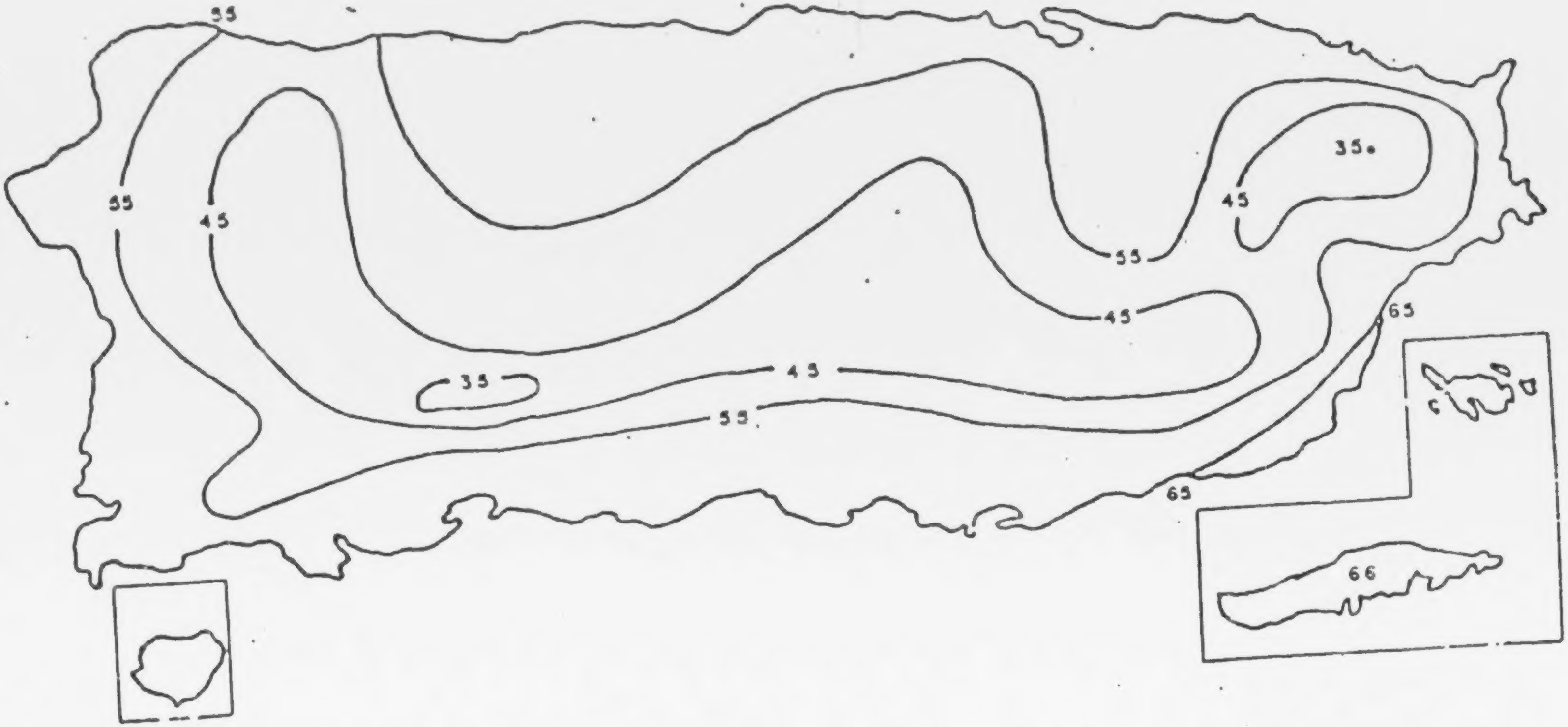


Figure 3. - Monthly average precipitation and evapotranspiration potential in the humid mountain region of Puerto Rico.

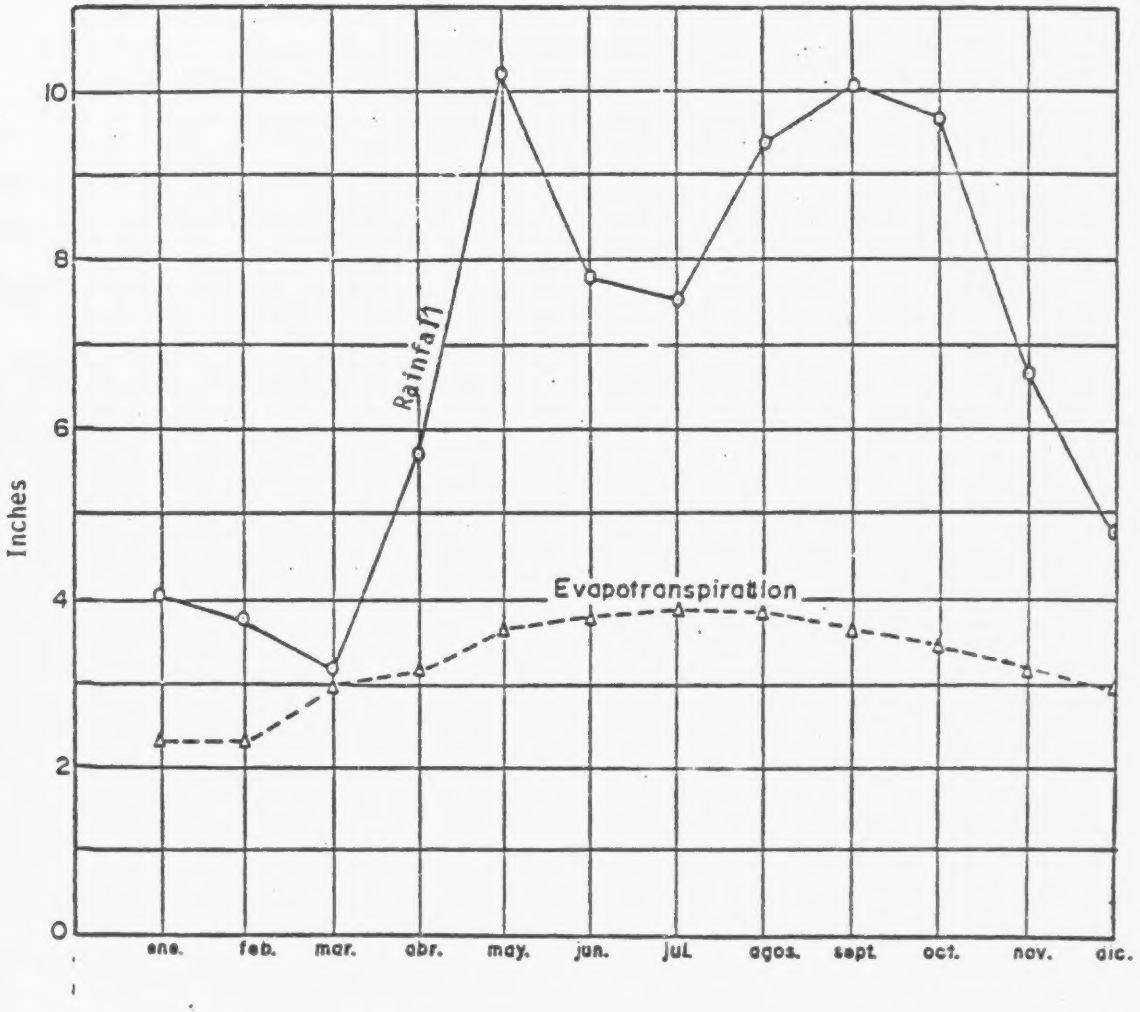
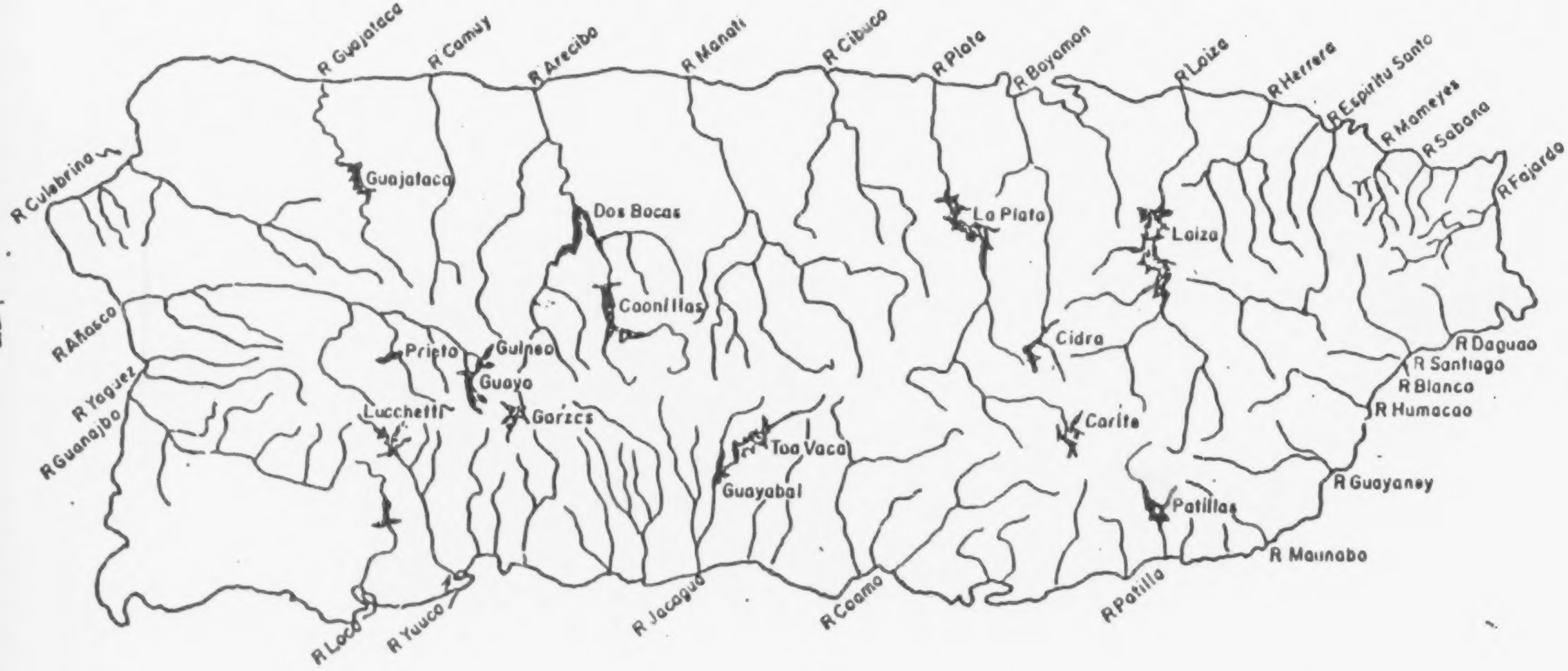


Figure 4. Location of the major rivers and lakes of Puerto Rico



BIBLIOGRAPHY

1. Anónimo, 1975. El Cultivo de la Caña de Azúcar en Puerto Rico, Est. Exp. Agr., Univ. P.R., Bol. 237.

2. Anonymous, 1977. Conjuntos Tecnológicos para la Producción de Distintas Cosechas, Est. Exp. Agr., Univ. P.R. - Papaya, Pub. 117; Gandures, Pub. 116; Caña, Pub. 103; Plátanos y Guineos, Pub. 97; Cítricas, Pub. 113; Mango, Pub. 114; Aguacate, Pub. 112; Piña, Pub. 106; Cosechas Farináceas, Pub. 101; Hortalizas, Pub. 102.

3. Anonymous, 1978. Consumo de Alimentos en Puerto Rico 1950-1974, Depto. de Agr. de P.R., Pub. Esp.

4. Anonymous, 1980. Islandwide Water Supply Study for Puerto Rico, 1980. Cooperative effort between the Commonwealth of Puerto Rico and U.S. Army Corps of Engineers.

5. Anonymous, 1982. Anuario Estadísticas Agrícolas de Puerto Rico, Departamento de Agricultura del Estado Libre Asociado de Puerto Rico.

6. Anonymous, 1982. Conceptos, Misión, Enfoque y Programa del Colegio de Ciencias Agrícolas para el Desarrollo de una Agricultura Moderna en Puerto Rico.

7. Barnett, A. P., J. R. Carreker, F. Abruña, W. A. Jackson, A. E. Dooley, and J. H. Holladay, 1972. Soil and nutrient losses in runoff with selected cropping treatments on tropical soils, Agron J. 64: 391-5.

8. Calero, R., G. E. Pringle, L. Muler, D. Vargas, A. A. Lloréns, G. Serra, L. R. de Zapata, E. González y G. R. Espinet, 1974. Estudio Socioeconómico del Programa de Fincas Individuales del Título VI de la Ley de Tierras, Est. Exp. Agr., Univ. P.R., Bol. 236.

9. Caro-Costas, R., E. Boneta and S. Silva, 1968. The effect of various cultural practices on yields of yams in Puerto Rico, J. Agr. Univ. P.R., 52(4): 356-61.

10. Caro-Costas, R. and J. Vicente-Chandler, 1980. Feeding Holstein cows exclusively on well managed tropical grass pastures, J. Agr. Univ. P.R. 64(1): 47-53.

11. Caro-Costas, R., J. Vicente-Chandler and F. Abruña, 1972. The effect of four levels of concentrate feeding on milk production by Holstein cows grazing intensively managed tropical grass pastures, J. Agr. Univ. P.R., 56(2): 99-103.

12. Conje, A. J., 1978. Virgin Islands Grain and Forage Sorghum Performance Trials, Virgin Islands Expt. Sta. Tech. Bull. No. 2.

13. Dhillon, P. S. and R. L. Park, 1974. Profitability of dairy farming in St. Croix, Virgin Islands Agric. Expt. Sta., Report No. 4.

14. Espinet, G. R., 1972. Costos y Prácticas en la Producción del Ñame (Dioscorea spp.) en Puerto Rico, 1967-68, Est. Exp. Agr., Univ. P.R., Pub. 78.

15. Espinet, G. R. y E. González-Villafañe, 1977. Costos de la Producción de Batatas en Puerto Rico en el 1975, Est. Exp. Agr., Univ. P.R., Pub. 109.

16. Espinet, G. R., E. González-Villafañe, L. Muler-Manzanares y O. Chavarría-de Gracia, 1973. Análisis Económico de la Producción y Mercadeo del Plátano a Nivel del Productor, Puerto Rico, 1971-72, Est. Exp. Agr., Univ. P.R., Pub. 82.

17. Gómez-Gómez, F. 1984. Water resources of the Río Grande de Manatí Valley, Puerto Rico, USGS Report 83-4199.

18. González-Villafañe, E., G. E. Pringle, M. I. Hernández, G. R. Espinet, D. Vargas-Hernández, J. E. Santini, L. Muler y R. Calero, 1972. Análisis Económico de 151 Fincas Establecidas a Través de la Administración de Hogares de Agricultores, Est. Exp. Agr., Univ. P.R., Bol. 232.

19. González-Villafañe, E., G. Serra, J. R. Calderón, G. R. Espinet, María I. Hernández, J. E. Santini y Z. Díaz-de Sumaza, 1971. Análisis de la Explotación Económica de Fincas de Café con un Area Total de 200 Cuerdas o Más, Est. Exp. Agr., Univ. P.R., Pub. 74.

20. Hupp, H. D., 1978. History and Development of Senepol Cattle. College of the Virgin Islands Report No. 11.

21. Jensen, F. E. and R. L. Park, 1974. Profitability of Hog Production in the U.S. Virgin Islands, Virgin Islands Expt. Sta. Report No. 6.

22. Lloréns, A. y J. Vicente-Chandler, 1976. Resultados Económicos de la Utilización de un Conjunto de Prácticas Tecnológicas en el Cultivo de la Papaya en la Zona de Altura de Puerto Rico, Est. Exp. Agr., Univ. P.R., Pub. 100.

23. Morris, S., 1977. Water Resources and the New Agricultural Plan for Puerto Rico, Greg Morris, P.R. Dept. of Natural Resources, San Juan, P.R.

24. Muler-Manzanares, L. y J. E. Santini, 1976. Estudio Socioeconómico de 29 Fincas Individuales del Título VI de la Ley de Tierras Distribuidas de 1967 a 1970, Est. Exp. Agr. Univ. P.R., Bol. 241.

25. Mullins, T. and R. W. Bohall, 1974. Fruits and Vegetables in the United States Virgin Islands, Expt. Sta. Report No. 2.

26. Ott, B., M. Rieve, R. Dietrich, and R. Kay, 1974. Grain Sorghum and Forage Production in St. Croix, Virgin Islands Expt. Sta. Report No. 1.

27. Park, W. L. and R. L. Park, 1974. Profitability of Beef Production in St. Croix, Virgin Islands Exp. Sta. Report No. 3.

28. Park, W. L. and R. L. Park, 1974. Potential Returns from Sheep and Goat Enterprises, Virgin Islands Expt. Sta. Report No. 7.

29. Pringle, G. E., E. González-Villafañe, D. Vargas, J. E. Santini, G. R. Espinet, L. Rodríguez-de Zapata y J. R. Calderón, 1973. Estudio Económico de la Producción de Pollos para Carne en Puerto Rico, Est. Exp. Agr., Univ. P.R., Pub. 80.

30. Quiñones, Díaz, Silva and Associates, 1979. Report on Studies of Water Supply for Rice Irrigation in the Lajas Valley Irrigation District. Consultants Commonwealth Department of Agriculture.

31. Quiñones, F., Eloy Colón-Dieppa and Max Juarbe, 1984. Flow Duration at Streamflow Gaging Stations in Puerto Rico, USGS Report 84-127.

32. Rivera, E. and H. Irizarry, 1984. Pigeon pea yields as influenced by planting date and pruning, J. Agr. Univ. P.R., 68(2): 173-8.

33. Roberts, R. C., 1938. Soil Survey of Puerto Rico, U.S.D.A.

34. Smith, R. M. and F. Abruña, 1955. Soil and Water Conservation Research in Puerto Rico, 1938-47, Agr. Exp. Sta. Univ. P.R., Bull. 124.

35. Somberg, S. I., 1976. Virgin Islands Forestry Research - A Problem Analysis, College of the Virgin Islands Report No. 9.

36. Stammer, R. W., 1974. Marketing Potential for Livestock Products in the U.S. Virgin Islands, Virgin Islands Expt. Sta. Report No. 8.

37. Torres-González, A. and J. Díaz, 1983. Water Resources of the Sabana Seca to Vega Baja Area, Puerto Rico, USGS Report 82-4115.

38. Vargas, D., J. E. Santini y L. R. de Zapata, 1975. Estudio Económico de la Producción de Cerdos, Puerto Rico, 1972, Est. Exp. Agr. Univ. P.R., Pub. 94.

39. Vicente-Chandler, J., 1974. Potencial y problemas básicos en la producción de alimentos en Puerto Rico, Presented and published Lydia Roberts Memorial Lectures, and by Surco y Cosecha, Vol. 1, 1974.

40. Vicente-Chandler, 1978. Conceptos, Plan y Programa para una Agricultura Moderna en Puerto Rico, Report.

41. Vicente-Chandler, J., F. Abruña, R. Caro-Costas, J. Figarella, S. Silva y R. W. Pearson, 1974. Intensive Grassland Management in the Humid Tropics of Puerto Rico, Est. Exp. Agr., Univ. P.R., Bol. 233.

42. Vicente-Chandler, J., F. Abruña, J. Lozano and S. Silva, 1985. Cultivo Científico del Arroz en Puerto Rico, P.R. Agr. Expt. Sta. Bull. (In press).

43. Vicente-Chandler, J., J. Abruña, J. Lozano, S. Silva, A. Rodríguez y C. T. Ramírez, 1977. Cultivo Intensivo y Perspectivas del Arroz en Puerto Rico, Est. Exp. Agr., Univ. P.R., Bol. 250.

44. Vicente-Chandler, J., F. Abruña y S. Silva, 1984. Experimentación y su Aplicación al Cultivo Intensivo de Café en Puerto Rico, Est. Exp. Agr., Univ. P.R., Bol. 273.

45. Vicente-Chandler, J., R. Caro-Costas, F. Abruña y S. Silva, 1983. Producción y utilización intensiva de las forrajeras en Puerto Rico, Est. Exp. Agr., Univ. P.R., Bol. 271.

46. Vicente-Chandler, J., R. Caro-Costas and E. Boneta, 1966. High crop yields produced with or without tillage on three typical soils of the humid mountain region of Puerto Rico, J. Agr. Univ. P.R., 50(2): 146-50.

47. Vicente-Chandler, J. and J. Figarella, 1962. Experiments on plantain production with conservation in the mountain region of Puerto Rico, J. Agr. Univ. P.R., 46(3): 226-36.

48. Vicente-Chandler, J., H. Irizarry y A. A. Lloréns, 1980. Costos e Ingresos en la Producción Intensiva de Plátanos en la Región Montañosa de Puerto Rico, Est. Exp. Agr., Univ. P.R., Pub. 137.

Background Paper No. 3

ASSESSMENT OF AGRICULTURAL PRODUCTION TECHNOLOGIES IN PUERTO RICO

by

Fernando Castillo-Barahona
and
Mohinder S. Bhatia

1986

Prepared for

U.S. Congress, Office of Technology Assessment,
Integrated Renewable Resource Management for U.S. Insular Areas,
Washington D.C.: U.S. Government Printing Office, 1987.

TABLE OF CONTENTS

Introduction...
Potential for Future Development of Puerto Rican Agriculture.................
Crop Production Technologies...
Promising Crops and Markets...
Policy Constraints and Recommendations...
Recommended Actions to Improve Puerto Rican Agriculture.....................
Bibliography...

ABSTRACT

At the same time that traditional crops--sugar cane, coffee and tobacco--have been declining, new agricultural industries such as livestock products, ornamentals and some vegetable enterprises have grown. Many factors have contributed to this growth, including favorable ecological and climatic conditions and infrastructure for Puerto Rican agriculture, local government support for agricultural development, increases in demand for food and non-food agricultural products and increases in personal income due to rapid industrialization and social support programs (e.g., Food Stamps). Despite this, Puerto Rican farmers produce only 37 percent of food products consumed locally.

A number of constraints hinder the continued growth of agriculture in Puerto Rico, including:

- abandonment of agricultural land
- high farm values
- high interest rates
- strong foreign and U.S. competition in local and export markets
- a fragmented industry structure
- decline in the farming population
- absence of experienced managers and modern technologies.

Agricultural research personnel and extension agents, as well as Puerto Rican farmers, lack experience with high yield agricultural technologies suitable to local conditions. In addition, large capital outlays are required in develop and implement the capital-intensive technologies required to maintain or improve the competitiveness of Puerto Rican agriculture.

INTRODUCTION

For about four decades, the Puerto Rican government has vigorously promoted the development of industry over the traditional mainstays of the economy--production of sugarcane, coffee and tobacco for export. These products contributed 64.3 percent of gross farm income income in 1950, and only 14 percent in 1985 (Puerto Rico Planning Board, various years). Industrial growth has been accompanied by a relative decline in the importance of agriculture to the Puerto Rican economy, which has changed from a low-income agricultural economy to a strong economy based on manufacturing. For example, farm income as a percentage of Puerto Rican Gross Domestic Product (GDP) declined from 24.0 percent in 1950 to 4.0 percent in 1985 (Puerto Rico Planning Board, various years), and rural unemployment is high. At the same time, gross farm income increased from $267.4 million in 1970 to $608.7 million in 1985, an increase of 228 percent.

Still, the rapid industrialization was accompanied by increases in population, urbanization and personal income, all of which contributed to strengthening certain agricultural markets. Consumer's eating habits also have changed. For example, per capita vegetable consumption was 50 lbs in 1975 and increased to 69 lbs. in 1983.

A factor contributing to the increased demand for food products in Puerto Rico during recent years has been the Food Stamp Program. This program was extended to Puerto Rico in late 1974 and its impact on food demand was felt within a few years. For example, the gross farm income generated by the Puerto Rican dairy industry equaled $99 million in 1974 and increased to $146 million by 1977. This amounts to a 47.5 percent increase, or an annual average growth rate of 13.8 percent. During this same period, the consumer price index increased 4 percent annually and population increased by 1.7 percent per year.

Further, the Puerto Rican government is supporting increased food production with dual goals of reducing imports and increasing employment opportunities. New legislation and regulations in agriculture have promoted the development of beef, pork and poultry. Specialized agricultural systems, such as production of ornamental plants, herbs, and hydroponic vegetables have grown in response to funds made available by the local government. All of these factors have encouraged farmers to develop and enlarge farm enterprises to satisfy greater demands for food and non-food farm products.

POTENTIAL FOR FUTURE AGRICULTURAL DEVELOPMENT IN PUERTO RICO

Puerto Rico has substantial potential to further increase food production both for local consumption and for export markets. Puerto Rico has a climate favorable to many crops such as rice, soybeans, fruits and vegetables. Puerto Rico also has sufficient water supply [ft: According to the Puerto Rico Department of Natural Resources the average annual rainfall for the entire Island is about 69 inches, varying from 60 inches along the northern coastal region to 100 inches at the Cordillera Central to about 35 inches along the southern coastal plain.] Skilled and unskilled labor are available and the University of Puerto Rico provides students with good training in agriculture. Its infrastructure is well-developed to support agricultural enterprises: processing, packaging and storage facilities are available. Substantial local markets exist and air and surface transportation systems are readily available for access to export markets. Despite the opportunities available, Puerto Rico still imports 63 percent of its food (Puerto Rico Planning Board, 1984).

Despite a scarcity of land in Puerto Rico, harvested land declined from 724,000 acres to 283,851 acres between 1959 and 1978 (Zapata, 1983). A study of abandoned farms concluded that abandoned farms commonly belong to persons over 50 who may farm part-time, but who derive much of their income from sources outside farming. Sometimes beef cattle are raised on abandoned lands which have returned to grasses. The causes of abandonment include lack of working capital, advanced age of the owner or a preferred source of income outside of the farm.

Major hindrances to the development of agricultural enterprises in Puerto Rico largely are economic. Some of these hindrances are described below:

(1) High Farm Value. Farm land can be purchased at about $5,000 per acre. This price is five times higher than the prevailing farm prices in the mainland United States. High farm values, with concomitant high interest payments, add to the costs of production. They also absorb much of the financial resources which otherwise could be used for upgrading farm equipment.

(2) High Interest Rates. Interest rated, in general, have been very high during the past several years. Puerto Rican farmers have been

particularly adversely affected, as they have very little capital and, subsequently, must borrow to finance chemicals, fertilizers, seeds, and other materials.

(3) High Cost of Production. The cost of agricultural production is high in Puerto Rico, mainly due to high water and electricity rates. Animal feed prices are high because of high costs of U.S. maritime transportation.

(4) Inadequate Management Practices. Puerto Rican farmers are not entirely conversant with modern farm business management. Their production technologies may be outdated, and they may not have an organized way to market their production. Farmers may not be keeping business accounts which would permit them to calculate profits and losses by product, by crop, and by individual parts of their farms.

A study conducted by the Agricultural Experiment Station (Zapata, 1983), estimated that 72 percent of Puerto Rican farmers hold property titles, and 83 percent held total power of decision. More than half of all farmers had at least one loan and half of those farmers had more than one loan from a credit institution. Ninety one percent of all farmers who had made loan requests had never been denied credit. In addition, 70 percent of Puerto Rican farmers have consulted with agronomists and 62 percent report that they have knowledge of agricultural techniques recommended to them.

(5) Unorganized and Fragmented Industry Structure. The agricultural sector of Puerto Rico is fragmented. Sixty-two percent of Puerto Rican farms are 20 cuerdas or less and 73 percent were less than 10 cuerdas. A large number of these farms produce agricultural products valued at less than $20,000 per year. Because farms are small, it is difficult for them to organize their production, marketing, finance and personnel administration practices. In addition, it is difficult for the farmers to standardize their products and, consequently, their products are not generally accepted by supermarkets. Farmers do not have transportation facilities which may permit them to transport their products to marketing centers. They have limited access to capital, while their need for capital is very high.

(6) Lack of a New Generation of Commercial Farmers. Puerto Rican youth are reluctant to enter the agricultural sector, primarily because farm incomes are much lower than their counterparts in non-agricultural businesses.

Farmers have a mean age of 55 in Puerto Rico. They have completed an average of seven years of school, although 17 percent have completed high school. Farmers reportedly locate only 90 percent of the workers they need; 52 percent of farmers report difficulty locating experienced workers and 39 percent say that the shortage of labor forces them to employ un-experienced farm workers (Zapata, 1983).

(7) Absence of Experienced Management. There is limited demand for experienced managers due to the prevalence of small farms in Puerto Rico; only 3.2 percent (1,025) of all farms have agricultural production valued at more than $60,000 per year and only 6.1 percent (1,944) of all farms have 100 or more acres of land. Managers of larger farms are expected to be highly educated with knowledge not only of farming, but also of business practices. People with such qualifications can command high salary employment in the non-farm sectors of the Puerto Rican economy and, as such, commonly are unwilling to manage a farm which may not be able to provide a comparable wage.

(8) Perception of Agriculture as a High Risk Business. It is generally believed that all firms operating within a declining industry have the same type of problems. While all businesses are confronted with risks, businesses in declining industries are perceived to have greater risks. Agriculture in Puerto Rico suffers from this dilemma.

(9) Perceived Status of Agriculture by Society. The role of agriculture has declined in the economy of Puerto Rico. The importance of sectors of manufacturing, commerce, government and other services has sharply increased. Along with the decline in agriculture, it is perceived that agriculture no longer is a profitable undertaking. Farms are lying fallow. This perception hides the fact that there are several successfully managed and operated farms, particularly the farms which are involved in the production of vegetables, fruits, livestock and poultry.

Agriculture research personnel and extension agents, as well as Puerto Rican farmers, lack experience in the implementation of sophisticated, high-yield agricultural technologies suitable to local ecological and economic conditions. For technologies that have been identified, the costs of developing and implementing high-yield technologies may limit their full development and implementation. For example, innovative vegetable producers report having expended $7 million for research and adaptation of crop varieties and agricultural systems to local conditions (Moore, 1985).

The acceptance of new technology by Puerto Rican farmers ultimately will depend upon its impacts on farm profitability. Thus, the crop farmer of the future will concentrate as heavily on the efficiency of resource (input) use as upon the volume of output. New technologies are needed to reduce production costs and maintain or improve production volumes.

CROP PRODUCTION TECHNOLOGIES

Four types of technologies have significant potential to provide Puerto Rico farmers with high yields without greatly increasing production costs:

(1) Intensification and mechanization of existing systems;
(2) Drip irrigation;
(3) Greenhouse systems; and
(4) Hydroponics.

Each of these systems are associated with different crops, although primary opportunities are in ornamentals, herbs and spices, and vegetable production for the U.S. "winter market" and to local markets to reduce imports of vegetable products, which at present amount to 83 percent of local consumption (Puerto Rico Department of Agriculture, various years).

Intensification and Mechanization.

Declining enterprises, such as sugarcane, coffee and tobacco, require intensification of production and reduction in costs in order to compete on world markets. Further, by intensifying these systems, their production can be concentrated on smaller areas of the most suitable lands without reducing their yields. For example, by siting sugarcane production on coastal flat lands, it is estimated that current production can be achieved on approximately two-thirds of the land currently planted. [This may, however, require an initial high capital outlay for land leveling.] The current coffee yield under a shade canopy system is 300 lbs. per acre per year. This could be increased to 12,000 lbs./acre/year using dense plantings, heavy fertilization and eliminating interplanted shade trees.

Drip Irrigation.

Yield of vegetables per acre using drip irrigation is reported to be two times greater than yields under traditional systems of canal and well irrigation. Drip irrigation also is being used in an experimental mango farm on the semi-arid south coast. This system is estimated to produce 10 million fruits each year on 500 acres (Moore, 1985). The higher prices available in the U.S. "winter market," when fruits and vegetables (e.g., tomatoes, lettuce, cucumbers, honeydew melons) produced on the mainland are in short supply, may provide the capital for farmers to invest in such systems.

Hydroponics.

Yields of vegetables produced hydroponically are even greater than those produced using open-field drip irrigation systems. For example, yields of hydroponic tomatoes are reported as high as 3,000 hundred-weight per acre, compared to 300 cwt/acre using drip irrigation and 120 cwt/acre under traditional systems (Moore, 1985).

Hydroponic systems require little land, but are extremely capital- and labor-intensive. High-value products such as fresh herbs and specialty herb products for the U.S. Hispanic market are particularly suitable for hydroponic systems. Coriander currently is produced hydroponically by one grower with high per acre yields and profits (personal communication, Mr. Greene, Corozal, Puerto Rico). In addition, vegetables grown for the U.S. winter market can be sited in mountainous regions using hydroponic systems.

Greenhouse Production.

Greenhouse grow-out systems are most prevalent in the high-value ornamental industry due to a USDA requirement that plants for export into the mainland U.S. have no soil attached. The largest producers also use other advanced technology such as drip irrigation and environmental controls. These sometimes are supplied by "pre-finished" plants grown in more traditional systems by "satellite farmers."

April-Agro Industries Agriculture Complex [ft: the entire section was derived from Estudios Technicos, Inc., Evaluation of Diversified Agro-Industrial Operations in the South Coast of Puerto Rico, 1985.]

April-Agro Industrial, conceived in 1977, was intended to promote agricultural development in the southern plain of Puerto Rico by producing fruits and vegetables such as tomatoes, peppers, squash, lettuce, cucumbers, cabbage, watermelons, and pineapples. These products were intended to substitute for imports amounting to $115 million in 1976. In addition, it was expected that the April-Agro project would generate technological innovations suited to the particular needs of Puerto Rico.

To accomplish its objectives, the project relied upon drip irrigation systems. The major advantage of these systems are efficiency increases under intensive farming. Drip irrigation systems are more efficient than sprinkler system by 13 percent, tube or pipe systems by 31 percent, furrow systems by 56 percent, and 'boulder for pasture' by 89 percent. For production of legumes and vegetables, drip irrigation proved to be the best form of irrigation for the following reasons:

1. It permits control of water applications, thus sustaining water at reasonable levels and guaranteeing continuous soil moisture;
2. Under drip irrigation, water does not come into direct contact with leaves, thereby reducing the incidence of pests, plagues and spoilage and, in turn, increasing the quantity of marketable products;
3. It permits the introduction of fertilizers and pesticides through the water, reducing operation costs; and
4. Its efficiency does not depend on esternal factors such as winds or topography and, therefore, it permits production of higher yields per acre.

However, the high costs of installation and high levels of technical management skills have constrained its application.

April-Agro has trained hundreds of Puerto Rican farm workers in the use of these spohisticated techniques. The workers were taught how to (1) define water deficits in the soil; (2) estimate required water volumes; (3) calculate the required duration of application; (4) keep records of calculations; and other related techniques. Some neighboring small farmers now are using these techniques.

A second important technological development has been the use of mulches. Plastic mulches have led to higher productivity through better control of moisture and humidity, protection from pests and by speeding up the photosynthetic processes of the plants.

The project made three additional contributions. First, the sale of the farm's production made it clear that a market for these products exists. Second, it was demonstrated that, through advanced technology, a sufficiently stable and high quality production can be achieved. The porject induced the supermarket chains to purchase and market local produce.

Another contribution of the project is the successful demonstration of the concept of interlinked large farms and small farms. Satellite farms, ranging from 38 to 120 acres, are operated by individual farmers using April-

Agro technology, packing facilities, pest control, marketing and fertilizing procedures. Plantings are coordinated among the satellite farms and with the April-Agro operation. By using common techniques and facilities, as well as centralized marketing and packing of the produce, it was shown that economies of scale can be achieved which otherwise would have been lacking.

PROMISING CROPS AND MARKETS

Traditional Crops: Sugarcane and Coffee.

Sugarcane yields declined from four tons/acre in 1955 to less than 3 tons/acre in 1985 in response to both production and milling inefficiencies (Moore, 1985). Similarly, the average per-acre yield of coffee in Puerto Rico could be increased 40-fold (from 300 lbs/acre to 12,000 lbs/acre) using modern, intensive techniques. Because of strong international competition and declining markets, these industries probably have little opportunity for significant expansion beyond supplying local markets. However, modernization, intensification and concentration of these crops to appropriate sites would ensure maintenance of current production levels and release land for other, potentially more profitable agricultural enterprises.

Milk.

Since 1969, the value of milk produced in Puerto Rico has surpasses the value of sugarcane, and now constituted the most important locally produced farm product (Puerto Rico Department of Agriculture, 1983). This can be attributed primarily to the "Milk Industry Legislation Act" establishing the Milk Industry Administration Office in the PR Department of Agriculture in 1956. The stable marketing conditions provided by this Act encouraged producers and processors to adopt new techniques and thereby increase production and distribution of milk. Large-scale, commercial dairy farms are displacing small-scale operations; in 1955, 45 percent of locally produced milk came from "first-class" dairy farms, growing to 88 percent in 1985 (Puerto Rico Department of Agriculture, 1983). Although Puerto Rico supplies most of its fluid milk demand, 90 percent of manufactured dairy products consumed in Puerto Rico are imported (Moore, 1985).

Beef.

Most beef produced in Puerto Rico is supplied as a by-product of dairy farms and by small producers. Few farms are devoted directly to commercial beef production, perhaps as a result of the ready availability of low-cost imports. Improved pasture in the mountainous regions might permit expansion of this industry.

Pork.

The pork industry similarly is restricted by low-cost imports. In addition, two-thirds of production costs must be spent on feed imported from the continental United States (Moore, 1985).

Poultry and Eggs.

Most broilers grown in Puerto Rico are produced and marketed under vertically integrated "contract" systems. Generally, the contracting company furnishes chicks, feed and medicine and technical advice. The grower supplies land, housing, equipment, labor and other inputs. The Contractor picks up broilers from the growers, processes them and sells them to distributors, fast-food restaurants and retail outlets. Growers are paid on a per-pound basis. Expansion of this industry could be achieved by expanding existing processing plants. Competitive disadvantages created by the high cost of imported feeds can be offset by using modern production and processing technologies.

Vegetables.

In general, local production of vegetables has declined in Puerto Rico since 1960. New technologies, such as drip irrigation and hydroponic systems may provide the product yields and quality needed to make these competitive with imported products.

Fruit.

Pineapples, with a farm value of $12.4 million, currently are produced for both local and export markets.. Avocado harvests valued at $2.7 million and citrus harvest worth $4.2 million currently are being harvested from diffuse stands planted in conjunction with coffee plantations (Moore, 1985). Papaya, watermelons and coconuts also are produced in Puerto Rico. Mangos. avocados, and citrus, in particular, could be produced economically in large quantities.

Bananas, plantains and root crops.

Bananas, plantains and root crops (tanniers, sweet potatoes, yams and cassava) are grown in small plantings in the humid regions of Puerto Rico. Although yields are low and most are consumed on the farm, the value of these products amounted to $57.4 million in 1985 (personal communications, Puerto Rico Department of Agriculture).

Rice.

The local rice industry was established in 1978 with the construction of a modern rice mill that currently mixes local rice (4% of output) with rough rice imported from the United States (96% of output) (personal communications, Puerto Rico Department of Agriculture). Seven farmers farm 3,500 acres of rice worth approximately $400/acre. Because large acreages and rich, flat land are required for profitable enterprises, the future of rice production in Puerto Rico is uncertain.

Ornamentals.

Ornamentals worth $14.5 million were produced in Puerto Rico in 1985 (Castillo, 1985). Most are exported to the mainland U.S., although a small percentage is exported to Europe. The ornamental industry is the largest agricultural employer per acre, and provides the highest profit per acre of any Puerto Rican agricultural industry. This industry requires a large capital investment per acre, varying with the type of plant produced and the production system used. Costs can range from $10,000 per acre under hydroponic systems to $200,000 per acre (Castillo, 1985). Employment also varies with the type of production system used, ranging from one to ten employees per acre. Unlike other products, however, this industry provides year-round employment and pays at least minimum wages to workers because the ornamental plants are sold in the U.S. mainland. Under U.S. laws the producer of a product entering interstate commerce must pay minimum wages.

In 1975, the PR Department of Agriculture instituted a program to associate "satellite farmers" with large ornamental producers to facilitate marketing. Small production systems, generally land units of 5,000 square feet, with an initial investment of $15,000 for equipment. In 1976, sales averaged $12,000 per unit, or which 30 percent ($3,600) were profits--a 24 percent rate of return on investment per year. (Castillo, 1985)

Demand for Puerto Rico foliage plants is increasing, due primarily to lower production costs in Puerto Rico than in the southern U.S. and other Caribbean countries, and to adverse weather conditions experienced in the southern U.S. in recent years (U.S. Weather Service, n.d.). The PR government plans to double ornamental production over the next five years (Puerto Rico Department of Agriculture, 1985). This will be made possible by additional credit, marketing and technical assistance facilities, as well as guaranteed loans. The Government of Puerto Rico will establish an office for this purpose in 1986.

Expansion of the ornamental industry represents a significant opportunity for Puerto Rico to expand exports and, thus, reduce trade deficits with the U.S. and foreign countries. Development of the ornamental industry could be accelerated by creating specialized laboratories to research concerns of ornamental agriculture, such as pest and diseases. In addition, these laboratories could develop tissue culture methods suitable to ornamental crops to reduce importation of seedling stock. Further, the Puerto Rican government could develop programs to promote Puerto Rican ornamentals in both the U.S. and foreign markets similar to programs conducted for industrial products.

Vertical Integration of Agricultural Systems.

The formation of integrated food production/processing/marketing systems is likely to be a successful method of increasing Puerto Rican food production. Contract farming is one method of vertical integration which extends benefits to small farmers as well as to large producers. The farmers own and operate their farms, the central operations units buy, process and sell the product, resulting in an integrated enterprise capable of capturing economies of scale.

Under this system, businesses contract with small farms to raise a specified amount of raw materials at a guaranteed price (and may produce materials themselves). To coordinate this system, the company determines product quantities required to fulfill identified consumer demands and maintain desired market prices. Commonly, the company provides farming inputs (e.g., fertilizer), some production assistance (technical and financial), and central processing facilities and marketing services.

Production and marketing contracts provide significant benefits to both producers and consumers (Puerto Rico Department of Agriculture, 1985):

(1) Small farmers can capture the benefits of economies of scale in processing and marketing, and so obtain greater returns than as independent producers.

(2) They allow farmers to make pricing decisions previous to delivery of the

products to market, so that price uncertainties are shifted from farmers to consumers.

(3) Farmers are given greater access to markets, which may be expanded through advertising and promotion underwritten by the central company.

(4) Consumers are assured of more standardized product quality, and perhaps access to a range of product quality at varying prices.

(5) Consumers receive relatively stable product availability and price.

Numerous examples of successful vertical integration of agricultural enterprises exist in Puerto Rico (Puerto Rico Department of Agriculture, 1985). For example, PRDA provides financial assistance to both the processing and distribution facilities and to "satellite farmers" supplying the broiler and ornamental industries. The ornamental industry is particularly suitable for small family-farm operations associated through a central producer serving as a technical assistance, quality control and marketing coordinator.

Significant agricultural assistance efforts should be directed to expanding current projects to serve as central producers so that the benefits of growth can be spread to small farming operations. Increased implementation of this system will provide additional income and employment opportunities for small farms units which have few opportunities to diversify to high income crops.

POLICY CONSTRAINTS AND RECOMMENDATIONS

Some of the recommendations made below may seem to conflict with prevailing United States policies on agricultural development, inter-state commerce and international trade, but the authors feel that Puerto Rican agriculture and markets force considerations that depart from traditional frameworks. In dealing with this, we should keep in mind that:

1. Many farm products grown or raised in Puerto Rico are not raised within the continental United States, e.g., coffee, plantains, bananas, pineapples, and most root crops.
2. The main government objective is not the production of agricultural products, but the creation and maintenance of employment opportunities. Agriculture is a large, direct employer and a large segment of the industrial and commercial activities depend on agriculture. Most consumer products derived from agriculture could be obtained elsewhere at cheaper prices than those grown or raised in Puerto Rico.
3. Farm programs in Puerto Rico are based on this objective. For example, the Puerto Rican Government will strongly support the establishment and operation of 50 farm units of 10,000 hens each for egg production, but probably would not support the establishment of five farms of 100,000 hens each. Ten dairy farms of 80 to 100 head of cattle is more attractive to the Government than one farm with 1,000 head. This might not be the best approach to obtain "volume efficiency," but it keeps more farmers active.
4. Puerto Rico is a "closed market for perishable agricultural products because of its isolation from other U.S. markets and the inherent difficultire in transporting products originating or received in Puerto Rico to other markets. For example, if a vanload of fresh tomatoes is received from Georgia, it is highly uneconomical and impractical to move it back to any other market in the U.S. So it has to be sold at a "distress price" in Puerto Rico. If a similar situation occurs in New York, the vanload could be moved to Chicago, New Jersey, Pennsylvania, etc. Many U.S. and foreign farm products are sold at distress prices, affecting the price stability for locally grown products.
5. The local market is used by many U.S. sholesalers as a market for

the dumping of inferior quality products. Many products are sold on consignment, at whatever prices the representatives of the U.S. wholesalers can get in Puerto Rico.

6. All tropical products are highly perishable and, thus, warehousing for long periods of time is not exonomically feasible in most of the cases.
7. Most U.S. traditional agricultural products, like wheat, barley and corn, are not natural to the Caribbean tropics.
8. Practically no animal foods are produced in Puerto Rico. As a result, livestock production is at a disadvantage compared to mainland producers. Animal feed must be imported. Prices for locally grown animal products reflect the transportation, port, warehousing and insurance costs.
9. Puerto Rican products must compete with similar products grown or produced in both the mainland U.S. and foreign countries. Puerto Rico finds itself at a disadvantage because of greater production efficiency in the mainland U.S. and much lower costs of production in competing neighboring countries.
10. Both mainland and Puerto Rican populations consume many farm products grown in foreign countries using pesticides which are not authorizxed for domestic use of U.S. health authorities (mainly because they are carcinogenic). What seems to be an appropriate limitation to our growers is not properly controlled in imports.
11. Mos food and other products are grown in the Puerto Rican highlands where steep topography renders the land unsuitable for intensive mechanization. In addition, the diversity of soil types in Puerto Rico make cultivation difficult.
12. Rainfall generally is adequate in both quantity and distribution for farming in the highlands. However, crop production in the southern part of the Island must depende entirely on irrigation, Water for irrigation purposes in this area is scarce. Water-saving techniques, such as drip irrigation, are not generally used by regular farmers.

RECOMMENDED ACTIONS TO IMPROVE PUERTO RICAN AGRICULTURE

There are a series of recommended actions for the U.S. Congress and executive branch afencies of the government, as well as for the government of Puerto Rico, private industry and academic institutions which should be undertaken in order to improve agricultural production and employment.

Congressional Actions

(1) Designate Puerto Rico and a center for the development and implementation of agricultural technologies suitable for tropical areas. This should be an independent center working very closely with the Puerto Rico Department of Agriculture, Agriculture Experiment Station, Agricultural Extension Service, and the Mayaguez Campus of the University of Puerto Rico. The Center may be named "Center for Research and Development of Tropical Crops, Livestock, Fruits and Vegetables." It should be funded with Federal grants, initially for a period of ten years. It should conduct research in all the tropical agricultural products and analyze and experiment as to what products can be commercially produced in PUerto Rico. It should analyze the use of fertilizers and other chemicals, as well as the use of machinery for the tropical climate. The Center should help improve agriultural production and employment in Puerto Rico, which then would (a) help reduce the need for imports, and (b) meet the rising demand for livestock, poultry, fruits and vegetables.

(2) Authorize use of a specific portion of Food Stamp funds (currently totaling $825 million per year) for transfer to an agricultural cost-sharing program administered by the government of Puerto Rico. If such funds were earmarked to supplement agricultural labor income, it could reduce migration of Puerto Rican farm workers to the U.S. mainland. This action will increase agricultural production and employment. It also will reduce dependenc, on the Food Stamp Program.

(3) Authorize Puerto Rico to establish quotas restricting imports into Puerto Rico of certain locally produced food products to reduce competition. Puerto Rico currently is authorized to establish tariffs on coffee imports to protect local growers. In 1931, the U.S. Congress authorized the Legislature of Puerto Rico to levy duties on import of coffee. At present, this duty is $2.10 per pound. The duty has proven to be helpful for coffee production in Puerto Rico. Like coffee, other products need to be protected. These products are potatoes, yams, yuca, gandules, etc. The protection could be limited to a period of ten years.

Federal Programs

(1) Appropriate additional funds to the Agriculture Research Service and Extension Service associated with the University of Puerto Rico to increase development and dissemination of appropriate agricultural technologies. A program of cooperative, on-farm research/extension projects should be instituted to develop and encourage implementation of appropriate technologies (including marketing techniques).

Puerto Rico Government Actions

(1) Allocate funds to finance new and existing commercial and semi-commercial farm projects. This can be done through the Industrial Development Bank which should soon be functioning.

(2) Establish a technical office to advise farmers in implementation of modern technologies such as irrigation systems, fertilization programs, and pest and disease control. The personnel of this office must be highly knolwedgeable in modern technologies.

(3) Support establishment of a laboratory to develop tissue culture techniques for ornamental plant, vegetable and herb industries.

(4) Revise fertilizer registration regulations to allow flexibility of application for different crops. For example, Puerto Rico fertilizer laws require a minimum of 24 units of N, P and K. Some ornamental foliage plants do not need this amount, so that the law serves only to increase the costs of production and increase water pollution.

In addition, regulations should be established to authorize use of chemicals approved by EPA and currently registered for use in the southern U.S., but not permitted in Puerto Rico.

(5) Special air and ocean freight discounted rates should be granted to exported agricultural commodities.

(6) Property tax exemptions, currently granted to most agricultural

industries, should be extended to ornamental producers. In addition, corporate income tax exemptions should be extended to farm operations oriented to export markets.

Private Industry

(1) Private banks could support agricultural development by allocating resources specifically for agricultural loans.

Academic Institutions

(1) Educational curricula should be developed to train agricultural managers and technicians in the new agricultural technologies.

BIBLIOGRAPHY

Castillo, L. Fernando, Feasibility Study to Expand Ornamental Production for T. Lockand, San Juan, Puerto Rico, 1985.

Estudios Tecnicos, Inc., Evaluation of Diversified Agro-Industrial Operations in the South Coast of Puerto Rico, 1985

Moore, Gene B., Propuesta para la Expansion de Hydroponics en Puerto Rico, 1985.

Puerto Rico Department of Agriculture, Program Agricola, September, 1985.

Puerto Rico Department of Agriculture, Facts and Figures on Puerto Rico's Agriculture, various years.

Puerto Rico Department of Agriculture, Office of Economic Studies, Estudio Economico Exhaustico do la Industria Lechera de Puerto Rico in 1982, August, 1983.

Puerto Rico Planning Board, Income and Product, various years.

Puerto Rico Planning Board, Economic Report to the Governor, 1984.

U.S. Weather Service, various press releases.

Zapata, J.Z. and others, El Mercado de Trabajo en la Agriculture y las Caracteristicas Socio-Economicas do los Obreros Agricola en Puerto Rico, Agricultural Experiment Station, October, 1983.

Personal Communications

Puerto Rico Department of Agriculture
    Office of Statistics
    Office of Economic Studies

Background Paper No. 4

ASSESSMENT OF AGRICULTURE CROP PRODUCTION TECHNOLOGIES IN THE U.S. VIRGIN ISLANDS

(Author's Draft)

by

Eric Dillingham

1986

Prepared for

U.S. Congress, Office of Technology Assessment,
Integrated Renewable Resource Management for U.S. Insular Areas,
Washington D.C.: U.S. Government Printing Office, 1987.

ASSESSMENT OF AGRICULTURE CROP PRODUCTION TECHNOLOGIES IN THE U.S. VIRGIN ISLANDS

by

ERIC DILLINGHAM

ABSTRACT

Agriculture was once a thriving industry in the Virgin Islands. Sugarcane was the principal crop for over a century. Since the industry collapsed in 1966 there has been a continuous decline in agriculture, which persists until the present. No new crop has since been incorporated on a commercial scale. The development of tourism, the increase in industrial and commercial activities, the expansion of local and federal government services and social welfare programs provide more desirable, higher-paying alternatives to agriculture labor. This has decreased crop production to almost nothing allowing importation to satisfy the continuously increasing demand for produce.

The general lack of agriculture support by the Virgin Island government has caused negative incentive to the islands few farmers. This lack of support has filtered down to their minimal financial support for federal matching funds provided to the Land-Grant programs.

Only a few local farmers adopt efficient high-yielding production systems, where as the majority are still utilizing subsistence farming methods. The subsistence farmer must adapt efficient production systems to economically survive.

Development of advanced agriculture technology is very limited. This is due in part to the lack of adequate experience within the Virgin Islands Department of Agriculture and the general negative attitude of local farmers to develop new advanced techniques.

The Virgin Islands Cooperative Extension Service and Agriculture Experiment Station are providing some technical assistance. Despite this there are constraints to the development of agriculture in the U.S.Virgin Islands which must be solved before local farmers can compete successfully with imports.

INTRODUCTION

Agriculture History

Classically, sugarcane was an important part of the economy. Since 1966 all operations have ceased. Finding suitable cash crops to replace it is difficult. Rapid urban expansion has intensified the limitations that already existed, among them the limited supply of land and water. Immigration from other Caribbean islands and the U.S. mainland is increasing.

"The retention of large volumes of rainfall in the soil zone from which it evaporated and transpired by plants greatly reduces the water available for recharge to the aquifer of the islands."[1] Emphasis must be placed on the use of low volume irrigation technology and mulches to utilize this limited resource to its maximum potential.

Current Crop Production

Food crops which are being produced on a very limited basis for local consumption include; tomatoes, cucumbers, eggplants, bananas, mangoes, avocados, citrus and herbs and spices.

Ornamental plants are being produced for the increasing tourism market. This industry has a good potential for development.

The majority of local produce is sold at roadside stands and in local market places. A very limited amount is sold to the hotels and restaurants and virtually none except for herbs and spices are sold at the large volume supermarkets.

There are a few commercial farms on St. Croix which produce vegetables all year around. These are small, 1-5 acres in size, and they utilize low-volume drip irrigation. Their water source depends upon small-diameter shallow wells, with water quality varying upon location and time of year.

"The high cost of land and steep terrains have forced the St. Thomas farmers to grow high value crops. The St. Thomians grow herbs and spices and bush tea that bring a good return."[2] Farming on St. Thomas is limited to very small areas consisting of 1/2 to 2 acres. A new advance-technology hydroponic system has recently been installed.

Food imports exceed $210 million annually in the Virgin Islands resulting in approximately 99% of the fruits and vegetables consumed. (Policy Guidelines-1980)

"Internal island economies have become easily penetrable by importing foodstuff, hence such agricultural products have become readily available substitutes for locally grown produced food."[3]

The attitude of the Virgin Islander to agriculture work has been conditioned from the beginning. It was built upon slavery. This is a major reason for the general negative attitude of most workers to farming.

"The conditions have caused our youth to associate farming with poverty and low social status and it severely inhibits their willingness to consider farming as a wholesome occupation. "[4]

Securing adequate supplies of labor has contributed to the general decline of agriculture. High paying industrial jobs, shift of agriculture workers to tourism, the increased employment of the local government and the development of social programs have shrunk the agriculture labor force.

Geography and Climate

A series of volcanic actions in the Atlantic Ocean basin formed the basal rocks of the Virgin Islands These rocks have been altered by additional intrusion of igneous rocks, by faltering, folding and uplifting. In places, mainly on the island of St. Croix, limestone has formed through the accumulation of shell and coral. As weathering continued, plant and animal decomposition formed the soils of the Virgin Islands.

The climate is maritime tropical, it is characterized by generally fair weather, steady winds, and slight range of temperature. A significant feature of the rainfall pattern is the marked variation within short distance with change in terrain and elevation.

Lifting of moist air over hilly terrain is the most common cause of rainfall on the islands. The average annual total rainfall varies between 20 and 60 inches, depending upon elevation and location.

The lower amounts are on the eastern ends of the islands, and the highest amounts are on the western slopes, due to prevailing easterly winds.

The temperature varies between a high of 87 degrees F in August to a low of 67 degrees F in January.

Regularity in the direction of the trade winds is one of the most dependable weather patterns on the islands. The islands are affected by tropical storms and hurricanes occasionally.

The Virgin Islands consist of St. Croix, St. Thomas and St. John and several smaller islands.

St. Croix, the largest island is approximately 22 miles long from east to west, and from 2 to 6 miles wide. The island is approximately 54,400 acres or 85 square miles.

The island of St. Croix is characterized by a mountainous area in the north flanked by a rolling plain to the south. The mountains are broken by many narrow, steep-sided valleys through which intermittent streams discharge in southerly and south-easterly coursed across the plain. Few deeply cut streams flow directly westward.

Mount Eagle is the highest point of St. Croix at 1,165 feet above sea level. The eastern is mountainous, the elevation is not as high and the streams are not so sharply incised.

St. Thomas the second largest island, is about 40 miles north of St. Croix. It is approximately 12 miles long and 3 miles wide. The area is approximately 19,000 acres or 30 square miles.

St. John is east of St. Thomas and is approximately 12,000 acres or 19 square miles.

St. Thomas and St. John have irregular coastlines, numerous bays, steep slopes and small drainage areas. For the most part the islands are mountainous. Coastal plains are almost absent. There are no permanent streams or rivers. Intermittent streams discharge into the sea, but on their way form narrow level alluvial fans and terraces. Crown Mountain, the highest peak on St. Thomas is 1,500 feet above sea level. Bordeaux Mountain, the highest peak on St. John is 1,277 feet above sea level.(U.S.D.A. Soil Survey, 1970)

Forecast Suitable Agriculture Systems

There is potential for increased development of fruits, vegetables, ornamentals and herbs and spices industries for local consumption in the Virgin Islands. Exportation of the food products does not seem feasible since they can be obtained from the States at a much lower production cost. The ornamental industry has a possibility for exportation due to the favorable climatic conditions of the Virgin Islands.

Agriculture crop production in the Virgin Islands, consist of four basic groups:

(1) The backyard gardener usually plants in the rainy season because of an insufficient continuous water supply. This group utilizes basic subsistence agriculture techniques.

(2) Several young Virgin Islands farmers support the Caribbean Rastafarian movement of natural organic crop production. These individuals make up a small but influential sector for potential agricultural development. They utilize basic subsistence farming practices with minimal technological advancements.

(3) The French farmers on St. Thomas provide a continuous supply of herbs and spices to the local markets and restaurants. They primarily grow high-value speciality crops.

(4) The forth and most productive group of farmers numbers less than 20 persons farming from 1 to 5 acres of land. They are considered the commercial farmers of the Virgin Islands. Only a few of them are able to earn their livelihood from full-time agriculture. Several have installed drip-irrigation and plastic mulches and utilize commercial fertilizers and insecticides.

Large-scale crop production is feasible on St. Croix but there are several restraining factors that have to be recognized and eliminated before this can become a productive industry.

CROP PRODUCTION TECHNOLOGIES SUITABLE TO THE VIRGIN ISLANDS

Backyard gardening

This is probably the most utilized form of crop production in the islands. It is highly encouraged by the Virgin Islands Department of Agriculture and is supported by the Cooperative Extension Service and Agricultural Experiment Station. Many people grow crops during the raining season to help reduce the need for supermarket foods. This practice would probably continue throughout the year if there was a continuous water supply.

A cheap and continuous potable water source is not available. Virgin Islanders are reluctant to use their cistern stored water for farming due to the high cost of replacement ($14-$50 per 1000 gallons).

The crops produced in a backyard garden consist of yams, okra, bananas, papayas, pumpkins and other common vegetables along with herbs and spices. Energy inputs and capital outlay are very minimal.

The majority of these farmers are not formally educated in agriculture, they rely on experience and knowledge handed down from generations. Many of the backyard gardeners utilize the services of the Cooperative Extension Service for insect and disease identification and recommendations for their control. The majority of the participants in the gardening workshops provided by the Virgin Islands Cooperative Extension Service are backyard gardeners.

Greenhouse Hydroponic Farming

Hydroponic operations have been tried several times in the Virgin Islands. One such operation was installed on St. Croix in 1980.

a. Case Study St. Croix

Farmers Home Administration (FHA) provided the capital of approximately $300,000. Two large greenhouses were constructed to grow tomatoes, cucumbers and lettuce for local consumption. The operation was designed by mainland standards with a high level of technological input.

This consisted of drip-irrigation, continuous nutrient feed solution and weekly applications of pesticides. The system also operated with a reverse-osmosis unit to remove the high salt concentrations in the well water. This project continued for a couple of years before production ceased.

Many factors contributed to its failure. The owner was not formally trained in agriculture and had no experience with hydroponics. The system required a prohibitive amount of electricity to produce the reverse-osmosis water. The greenhouses became increasingly infested with diseases and insects to the point where economical pest management was not possible.

b. Case Study St. Thomas

"Hydro-Farms", is a new installation of greenhouse hydroponics in the Virgin Islands. The system was installed approximately 18 months ago on St. Thomas to provide fresh tomatoes, cucumbers, lettuce and peppers to the local consumer.

"The capital outlay requires approximately $20,000 per greenhouse for set-up and planting of 1,000 tomato plants which should produce an estimated 850 lbs. per week." (John Young, Personal Communication) Hydro-Farms is the only recirculating water system used for large scale crop production in the Virgin Islands. Due to the serious water problems associated with agriculture, this method of production could provide an effective alternative to standard production methods.

Hydro-Farms is family operated. Financing has been provided by the Small Business Administration, Farmers Home Administration, personal funds and other private sources. Mr. Young does not have formal agriculture education, he obtains information and assistance from other similar hydroponic operations in the United States. Hydro-Farms is able to provide a desirable high quality product by incorporating advance technology while conserving water, the most limiting factor of crop production.

Since land values are so high, especially on St. Thomas and St. John, hydroponics would be the most suitable method of moderate-scale production. No emphasis has been placed on hydroponic farming by the Virgin Islands Department of Agriculture or the Land-Grant programs.

Small Landholders - St. Croix

This category accounts for the largest amount of crop production. Farms range in size from 1/2 to 5 acres.

Island Fresh Farms on St. Croix, is among the few which utilizes advance technological input to produce a continuous supply of fresh produce. This farm incorporates drip-irrigation, water catchment/storage facilities and small diameter wells to help alleviate water shortages.

Intercropping of vegetables and fruit trees is practiced, as is no-tillage and pest control. Crops grown on this farm are tomatoes, cucumbers, eggplants, citrus, avocados and mangoes. Vegetable crops are planted on a rotational basis to provide continuous production for local consumption.

The capital outlay consists of approximately $50,000 provided through FHA assistance program. Energy inputs are minimal since water is gravity-fed through the drip irrigation system. Soluble and granular synthetic fertilizers are used. Insecticides, fungicides and herbicides are utilized as needed.

The owner is formally trained in agriculture with a B.S. degree in Horticulture, Peace Corps experience, and 9 years of tropical agriculture experience.

Intercropping systems are commonly used throughout the Caribbean, but very few utilize all the aspects of advance technology as Island Fresh Farms. These systems are more suitable on St. Croix where land is still relatively inexpensive. Environmental impact is minimal since the area of land in production is so small. By incorporation of no-tillage, erosion of valuable top soils is minimized. Similar no-tillage systems are being used in the States. The use of commercial agriculture chemicals and fertilizers is contrary to the "organic" philosophy of local young farmers. There are a few other farms on St. Croix which use similar production practices.

Small Landholders - St. Thomas

"The herb farmers of St. Thomas produce a wide array of native seasoning and tea bush and provide fresh herbs to the many fine restaurants specializing in exotic cuisine. These products are also shipped regularly to consumers on St. Croix and the British Virgin Islands. St. Thomas herb farmers include a wide variety of crops, a practice which decreases both pest infestation and economic risk. Crops include tea bush like japona, inflammation bush and wormgrass, and plants used for both tea and seasoning like basil, mint, peppermint, tarragon, parsley, and dill."[5]

The St. Thomas herb farmers are a unique group. They utilize intensive intercropping of herbs and spices among bananas on steep terraced plots. Since most of these farmers are using rented lands provided by the Virgin Islands Department of Agriculture, or family owned land, initial outlay of capital is low. The labor consists of the owner and maybe one other employee. It would be impossible for these farmers to purchase this land since it is extremely expensive real estate, approximately $50,000 per acre and up depending upon improvements and views.

Advance technology has generally not been adopted. Drip-irrigation is still not being used. Minimal use of pesticides to control insects and application of synthetic fertilizers to improve soil fertility are the only exceptions. Local farmers use the Virgin Islands Cooperative Extension Service for problem diagnosis or identification, soil fertility testing and irrigation water analysis.

The herb farmers have no formal education in agriculture. Their's is a learning experience passed on from generation to generation.

The feeling among the old farmers is not to encourage the next generation to continue this trade, as their only means of support, but only as a second form of income.

Terrace farming is successful and is utilized throughout the Caribbean on a small scale. Increased applications of these systems would only provide a few individuals with employment and it would have little affect on the importation of produce.

Terracing, contour planting and keeping the soil covered are all essential to soil conservation on these islands. Erosion is a major problem of agriculture and development. This can be reduced by terracing steep slopes.

The herb farmers have little direct impact on the environment, other than providing erosion controls and making the land productive.

Rastafarian Agriculture

"A recent growing farm group in the islands consists of young adults seeking alternative independent lifestyles. They have invested untold time and effort to make the land productive.

They have terraced, brought in soil, and installed water systems. These improvements have been made with no security of tenure, making land and water their concern."[6]

"Growing primarily traditional crops, these young farmers have insured a higher price for their produce by marketing organically grown fruits and vegetables to a health-conscious populace."[6]

These young adults grow primarily subsistence crops, such as: okra, collard greens, pumpkin and herbs which are intercropped with fruit trees that are common to the area, these being sugar apple, mango, avocado, guava, and guava berry. Energy input is minimal. The only capital expenditures are for seeds and hand tools. The educational skills of these farmers is usually high school, with no formal agriculture training.

This subsistence, organic farming is associated with the youth movement in the Caribbean known as Rastafarianism. Their agriculture potential is limited to production for home use and some sales to the community. Increases in capital or technical assistance would probably only provide short-term employment and production.

This agriculture system has a very minimal environmental impact since the total acreage is small and they oppose the use of synthetic chemicals.

Case Study of Rastafarian Agriculture

"In May of 1982, Ujamaa Organic Gardens, Inc., a duly established non-profit corporation of the Virgin Islands submitted an application to the Community Development Programming Unit of the Virgin Islands Planning Office for a U.S. Department of Housing and Urban Development (HUD) Community Development Block Grant to organize and operate an economic development training program in agriculture to assist unemployed youth."[7]

"On August 16, 82, a grant in the amount of $195,000 was awarded to Ujamaa to establish and implement their proposed program. The program was a joint effort by Ujamaa and the Cooperative Extension Service, the latter providing classroom instruction, while members of Ujamaa provided "hands on" field experience in the planting and harvesting of selected native crops. Additionally, the Virgin Islands Department of Agriculture assumed responsibility for providing technical assistance including clearance of the work site and provision of adequate water facilities."[7]

"Ujamaa, through its training program, provided skills in organic farming and agri-marketing techniques to twenty-four unemployed youths, allowing them the opportunity to become self-supporting."[7]

"The project was doomed from the start. The Planning Board imposed upon them more that their original needs. The local government bent over backwards to accommodate them."(Sue Higgins, personal communication, 10-15-85)

The training program finished in one year and the continuation of the project was abandoned. The necessary water was never provided as agreed in the original lease from the Department of Agriculture.

The project was not well planned or studied in advance by other local agencies that could have provided additional assistance. There is a feeling among the local community to support Rastafarian youth because they express a desire to return to agriculture. Without input from all agencies and individuals that have agriculture experience and knowledge it is difficult to expect any project of this nature to be successful.

Intensive Monocrop Farming

The agriculture background of the Virgin Islands was built on intensive monocropping of sugarcane. Since the industry collapsed in 1966, no replacement crops have yet been substituted.

At present, there are no monocropping farming systems in the

Virgin Islands. Monocropping systems could be incorporated only on St. Croix. The steep terrain, the nonexistence of large tracts and high value of lands on St. Thomas and St. John makes it economically unfeasible.

Many types of vegetable and fruit crops could be grown on St. Croix. This would require considerable amounts of capital for mechanization, advance technology, labor and energy inputs, all of which are necessary for an intensive monocropping system. The products from this system could off-set the importation of only certain vegetables and fruits. Virgin Islanders would still be required to import all the remaining items.

Monocropping systems have been undertaken in Puerto Rico with some success. Two Israeli vegetable farms focus on the seasonal production of honeydew melon, peppers and tomatoes on about 4,000 acres and appear to have achieved profitable levels of production on these crops. (Morris 1985)

Provided a large monocropping system utilized advanced technology methods, environmental impact would be minimal. Reducing tillage, utilizing mulches and implementing an integrated pest management system could reduce erosion, water loss from evapotranspiration, and reduced chemical uses, respectively.

POTENTIAL FOR DEVELOPMENT OF A NEW AGRICULTURE INDUSTRY

Ornamentals

The cultivation of flowers and foliage plants in the Virgin Islands is left mostly to the home gardener and local horticulture clubs, and a few small nurseries. In an environment like the Virgin Islands there is a great potential for production of ornamental plants. Many plants are grown in the U.S. and shipped to the Virgin Islands and other Caribbean areas.

The neglect of ornamental horticulture in the Virgin Islands may be derived from the plantation agriculture system originally practiced, in which a few crops were mass produced. Since the collapse of the sugar industry, and the development of an industrial economy, there is an increasing demand for food crops. Ornamental horticulture has not evolved in the same direction. Ironically, Caribbean horticultural teaching and training programs have developed along the same lines.

"There are two immediate constraints; the lack of suitable institutions in tropical ornamental horticulture and the almost zero incentive for graduates in this field."[9]

Tourism is a large economic factor in the Virgin Islands. There is an increasing demand for hotels, which have extensive landscapes. The production of ornamentals for landscaping and interior decorating can be exploited. This would provide employment opportunities, as well as an import substitution commodity. The development of ornamental horticulture could provide environmental and economic gains for the Virgin Islands.

SUMMARY - PRINCIPAL CONSTRAINTS AND OPPORTUNITIES

Despite the availability of technical assistance and the potential productive agriculture land, there are several constraints to the development of commercial agriculture in the United States Virgin Islands. These constraints must be realized before local farmers can compete with imports.

1. Government Policy Plan

A long range government agriculture plan for the Virgin Islands does not exist. "The formation of a policy for agriculture in the Virgin Islands is two-fold. First, concern is the creation of an instrument with precise initial steps to insure a beginning and a format for advancement in agriculture. The second concern is a carefully planned long-range program with flexible objectives that can be measured on a periodic basis."[10]

"If impetus is to be given to the development of agriculture, innumerable agencies, businessmen and farmers will constantly be making decisions that commit the resources of the territory, in some cases for long periods of time. It is therefore necessary to have a frame of reference based on concepts, plans and general goals to serve as a base for agriculture development. The first step is to clearly define the mission of agriculture, determine the concepts in which its development is based, set specific goals and generate plans and programs to obtain these goals within a definite period of time."[11]

2. Lack of Land

Seventeen percent of the land categorized as agriculture use in the Virgin Islands is suitable for crop production. These lands must be identified and reserved from land development. Most of the land is semi-abandoned. There are large tracts of agricultural land on St. Croix owned by persons who do not want, nor need, or are not in a position to put this land to maximum use. The land should be identified and arrangements made to make it available for agriculture. Rent and lease agreements could be made to individual farmers.

The government of the Virgin Islands has recently purchased 2,044 acres known as Harvland for multiple use, including agriculture development. This land is considered the most fertile tillable acreage on St. Croix. The primary restraint to the Harvland development has been the lack of funds by the Department of Agriculture to survey, clear the land, and provide an adequate water source. This land has a good potential to produce viable small scale farming operations once it becomes available.

3. Credit and Financing

Financing for agriculture in the Virgin Islands is available through three main sources; the Farmers Home Administration, the Small Business Administration (SBA), and the Small Business Development Administration (SBDA). These sources are excellent because they provide reasonable interest rates and pay back periods. Another important feature is they provide consultation and other technical assistance.

Farmers Home Administration is somewhat reluctant to provide agriculture financing. Several large loans were made in the past that have not accomplished increased agriculture production.

Private banking institutions do not provide loans for agriculture related investments.

To develop agriculture financing, it will be necessary to identify sources of low-interest loans and make available grants to assist qualified farmers with start up capital.

4. Trained Personnel

One of the most pressing needs of Virgin Islands farmers is advanced technological assistance. The College of the Virgin Islands provides limited assistance. Research and experimentation at the Agriculture Experiment Station sometimes does not focus on the immediate needs of the farmers. It would be necessary to direct research in this area in order to address the needs of the Virgin Islands farmers. Educational programs at the primary, secondary, and college levels should be emphasized and assistance oriented toward agriculture development.

The technical training and assistance capabilities of the Department of Agriculture, the College of the Virgin Islands Cooperative Extension Service and Agricultural Experiment Station should be increased in order to serve the current and future needs of the local farmers.

5. Inadequate Water Supplies

There has been little effort by the Virgin Islands government to the conservation of rainfall. Every year water is wasted through surface runoff, evaporation, and transpiration by deep rooted trees and bush. It is estimated that 97% of rainfall is lost, which reduced to a daily basis, amounts to 96 gallons per acre per day. (Policy Guidelines-1980)

Only a small amount of the total available water from rainfall is stored in earthen dams for agriculture use and the majority of these dams are utilized for livestock watering, providing no stored water for crop production.

It is essential to develop a cost-efficient water source for irrigation through the additional construction of dams, reservoirs, storm run-off catchments, well fields, and by using waste-water supplies where feasible. Additional runoff can be reduced by terracing the steep hillsides for increased crop production. The reduction of useless vegetation by substituting it with grasses can also help decrease evapotranspiration.

Incorporation of efficient low-volume drip irrigation systems, along with mulches, is necessary to conserve this precious resource.

6. Marketing

Any significant increase in the production of agricultural products will require a complementary increase in marketing facilities and services. There is a need for a centralized place where farmers can bring their produce for storage, processing, and distribution on all three islands. A significant market and demand exists for locally grown produce.

The introduction of a farmers market centrally located near other shopping areas would allow the local farmers more exposure and facilitate the distribution of their products.

7. Appropriate Research and Technology

The Land Grant programs at the College of the Virgin Islands have been in existence since 1972. During the past 10 years the Agriculture Experiment Station has developed into a small research station with projects in agronomy, horticulture, pest management, plant pathology, irrigation technology, animal science, and aquaculture. An Associates of Arts degree in Agriculture is provided in the curriculum of the College and the Cooperative Extension Service is functioning on all three islands.

Several of the research projects need to be reviewed for their application to agriculture in the Virgin Islands. Experiments such as basic variety trials have been duplicated several times.

General lack of supervision and directional policies has allowed research scientists to conduct experiments without keeping adequate records on file. This forces the replacement scientist to conduct basic research over and over again.

Some research programs such as sorghum, papaya disease, and aquaculture do not support any related farming operations in the Virgin Islands. Increased technical training assistance and research should be directed to serve the current and future needs of farmers in the territory.

CONGRESSIONAL ACTIONS

The federal government has played a leading role in the advancement of agricultural technology throughout the history of the Virgin Islands. Technological advancement is a key role which the federal government can emphasize. Further agriculture development could be assumed through existing administrative structures, provided there is direct federal supervision and budgetary increases specifically earmarked for agriculture crop development programs.

Federal Programs

The most important federal programs which support agriculture development are the Cooperative Extension Program and Agriculture Experiment Station which are administrated through the College of the Virgin Islands. These programs have provisions for cooperative projects with local farmers. This provides an appropriate avenue for the development of advance agriculture technology in the Virgin Islands.

If the Agriculture Land Evaluation and Site Assessment program of the U.S. Department of Agriculture Soil Conservation Service is implemented, it could help local government determine suitable agriculture lands.

Increased financial support should be given to the newly enacted Eastern Caribbean Center associated with the College of the Virgin Islands. The ECC could provide an ideal situation to serve as a testing ground for adaptation of U.S. agriculture technology and it's transfer throughout the Caribbean.

The Caribbean Basin Initiative (CBI) has not yet inhibited agriculture development in the Virgin Islands. The majority of food importation comes directly from the U.S. mainland. The lifting of importation quotas for agriculture products from non-U.S. territories has not, and probably will not, affect the production of food crops. The only local industry that is directly affected by CBI is rum production.

RECOMMENDED ACTIONS TO MITIGATE PRODUCTION CONSTRAINTS

Federal Government

Federal financial assistance should be provided over a five year period to fund research and extension projects with qualified Virgin Islands farmers. Specialist and support activities should be developed in conjunction with the U.S.D.A.- Agriculture Research Station on St. Croix. These projects should be administrated through the existing institutions.

Projects should be of commercial scale and researched on private farms. They should focus on the development and application of advance technology.

These projects must be repeated for several years to demonstrate their success and permit refinement in techniques. The cost of materials, supplies and some labor should be provided in the agreement as an incentive to the farmers to take the risk. Local research and Extension personnel should be augmented with USDA specialists. All data carefully documented and distributed to farmers.

The goal of the projects is to develop economically viable crop production technologies and to distribute the information among other interested Virgin Islands farmers. The previous recommendations must be closely coordinated with the local government.

Local Government

The following recommendations were developed by the Virgin Islands Planning Office:

(1) Design and implement educational programs and assistance oriented toward industrial and community gardens.

(2) Develop cost-efficient water sources for irrigation by constructing dams, reservoirs, storm run-off catchments, well fields, and by using waste-water to recharge ground water supplies (if feasible).

(3) Construct irrigation systems where they are cost-effective.

(4) Increase the technical training and assistance capabilities of the Department of Agriculture and the Cooperative Extension Service of the College of the Virgin Islands in order to serve the current and future needs of farmers.

(5) Purchase and place on loan essential agriculture equipment which is, because of cost constraints, unavailable to local farmers.

(6) Purchase farm commodities such as seed, feed, farm implements in bulk, and resale them to local farmers at cost.

(7) Develop a crop insurance program against weather and theft.

(8) Establish agricultural facilities for the storage and processing and distribution of agriculture products on all three islands.

(9) Design and establish a well equipped farmers market to serve the special marketing needs on all three islands.

The territorial government must provide financial and technical assistance and develop an infrastructure in order for these programs to be successful.

EXPECTED CONSEQUENCES OF RECOMMENDED ACTIONS

"Once agriculture land is committed to an alternative use, it is extremely unlikely that it will ever be returned to the productive agriculture domain."[12]

A public survey was conducted in which 91% of the public surveyed felt that it is important for the government to exert efforts to expand agriculture. (Mills 1979)

Given this strong public support it is necessary to reverse agriculture's deterioration. This will demand resources and support by the territorial government. Expanding agriculture will provide several positive consequences.

It will tend to stabilize the social system, preserve the environmental, recreational and commercial activities and enrich the natural beauty of the islands. It can provide a more diversified, productive base, and reduce food import dependency.

"Finally the survival of agriculture may provide a continuity with past traditions of rural stability that luxury tourism and the capital intensive heavy manufacturing enclaves have violated."[13]

These recommended actions should provide the necessary incentives for development of agriculture crop production in the United States Virgin Islands.

FOOTNOTES

1. Jordan, D.G. "A Survey of the Water Resources of St. Croix Virgin Islands" U.S. Department of Interior 1975, p.5

2. Matuszak, J. "Intensive Agriculture on a Tourist Island" Videotape, Cooperative Extension Service of The Virgin Islands, 1985

3. Mills, F.L. "Comparative Considerations Between United States and Caribbean Farming Systems" 11th Annual Agriculture and Food Fair of the Virgin Islands Journal 1981 p. 14

4. Ibid, p. 13

5. Matuszak, J. "Intensive Agriculture on a Tourist Island" Videotape, Cooperative Extension Service of the Virgin Islands 1985 p.2

6. Ibid, p. 13

7. Cuthbertson, C.R. "An Exemplary Project" Virgin Island Planning Office, A Community Development Program 1983 introduction

8. Morris, G.L. " Assessment of Semiarid Agriculture Production Technologies for the U.S. Affiliated Caribbean Islands" Office of Technology Assessment Unpublished Document July 1985 p.3

9. Ramcharan, C. " Ornamental Horticulture The Missing Link" 14th Annual Agriculture and Food Fair of the Virgin Islands Journal 1984 p. 31

10. Shulterbrandt, R. "Policy Guidelines for the Development of Agriculture." Government of the Virgin Islands. 1980 p. 1

11. Ibid. p. 2

12. Mills, F. L. "The Decline of Agriculture and the Projection of the Number of Farm Units in the Virgin Islands." 20th Annual Meeting of the Caribbean Food Crop Society Proceedings. 1984 p. 30

13. McElroy, J. L. "Agriculture Potential in the United States Virgin Islands." 8th Annual Agriculture and Food Fair of the Virgin Islands Journal 1978 p. 20

PERSONAL COMMUNICATIONS

Mr. John Young, Hydro-Farms, St. Thomas, U.S. Virgin Islands

Ms. Sue Higgins, Virgin Islands Planning Office St. Thomas, U.S. Virgin Islands

REFERENCES

Anonymous, "Comprehensive Policy Plan" Virgin Islands Planning Office, Government of the Virgin Islands. September 1983

Cuthbertson, C.R. "An Exemplary Project" Virgin Islands Planning Office, Government of the Virgin Islands. 1983

Jordan, D.G. " A Survey of the Water Resources of St. Croix Virgin Islands United States Department of Interior 1975

Kean, O. " Expanding Agricultural Sector of the Virgin Islands Economy" 8th Annual Agriculture and Food Fair of the Virgin Islands Journal 1978

Matuszak, J. "Intensive Agriculture on A Tourist Island". Videotape, Cooperative Extension Service of the Virgin Islands 19'85

McElroy J.L. "Small Scale Agriculture in the Virgin Islands" 20th Annual Meeting of the Caribbean Food Crops Society Proceedings1984

McElroy, J.L. "Agricultural Policy in a Scarce and Fragile Environment" 9th Annual Agriculture and Food Fair of the Virgin Islands Journal 1979

McElroy, J.L. "Agricultural Potential in the U.S. Virgin Islands" 8th Annual Agriculture and Food Fair of the Virgin Islands Journal 1978

Mills, F.L. "The Decline of Agriculture and the Projection of the Number of Farm Units In the U.S. Virgin Islands" 20th Annual Meeting of The Caribbean Food Crops Society Proceedings 1984

Mills, F.L. "Public Evidence of A Vigorous Agriculture Program" 9th Annual Agriculture and Food Fair of the Virgin Islands Journal 1979

Morris, G.L. "Assessment of Semiarid Agricultural Production Technologies for the U.S. Affiliated Caribbean Islands" Unpublished Document O.T.A. 1985

Padda, D.S. "Developing A Viable Agriculture Industry in the Virgin Islands" 9th Annual Agriculture and Food Fair of the Virgin Islands Journal 1979

Ramcharan,C. "Ornamental Horticulture The Missing Link" 14th Annual Agriculture and Food Fair of the Virgin Islands Journal 1984

Rivera, L.H. & Federick, W.D. "Soil Survey of the Virgin Islands of the United States." U.S.D.A. Soil Conservation Service 1970

Shulterbrandt, R. "Policy Guidelines for the Development of Agriculture of the Virgin Islands" Government of the Virgin Islands Department of Agriculture 1980

United States Department of Commerce "1982 Census of Agriculture, Virgin Islands of the United States

Background Paper No. 5

ASSESSMENT OF LIVESTOCK PRODUCTION TECHNOLOGIES IN THE U.S.-AFFILIATED CARIBBEAN ISLANDS

by

Ruben Caro-Costas

1986

Prepared for

U.S. Congress, Office of Technology Assessment,
Integrated Renewable Resource Management for U.S. Insular Areas,
Washington D.C.: U.S. Government Printing Office, 1987.

POSSIBLE ACTION BY FEDERAL GOVERNMENT

1. Assign a specific proportion of the Federal Food Stamp funds (PAN), or other funds, to the Agricultural Extension Service ear-marked specifically for setting up demonstration farms and train personnel "on hands" to aid in the transfer of the most appropriate livestock production technology to farms throughout the Island.
2. Assign additional funds to the tick erradication program so that it may be put into effect Islandwide and be completed in a short period of time. The present erradication program by regions will take many years and will probably not be successful considering the large number of roads throughout the Island (about 9,000 miles of roads in an island 3,400 miles square). It also requires more effective implementation and coordination between the agencies involved.
3. Assign funds for incentive payments to farmers for planting pastures on steep lands in order to control erosion and increase livestock production and tie to programs of supervised credit.

ABSTRACT

There are about 270,000 acres of mechanizable lands with sufficient water for the production of a wide range of crops, about 100,000 acres of which are in pastures, primarily for dairies. There are also 600,000 acres of partially mechanizable lands in the humid region with deep soils and sufficient rainfall for most perennial crops. The best use for most of this land is pastures for milk and beef production since they protect the soils against erosion, do not require complex mechanization and are drought tolerant.

The Islands are almost self-sufficient in fresh milk with a production of about 380 million liters yearly. About 170 million liters are imported dry or condensed and about 6 million as UHT milk. There are about 110,000 cows and 600 first class dairies with 130,000 acres in pastures and 10,000 in grasses for cutting. Pastures are under-fertilized and mismanaged and excessive amounts of expensive imported concentrates are fed, an average of over 1.5 pounds/liter.

It has been shown that the first 10 liters of daily milk production can be produced with grass alone with additional production supplemented with concentrates. Also, that intensively managed grass pastures can carry one milk cow per acre or 2 beef type animals producing over 1,000 pounds of gain in weight yearly.

About 45.7 million pounds of beef are produced locally and 73.4 million are imported fresh or frozen yearly. Much of the local beef comes from dairies and from cattle raised by small farmers and the remainder from range land in the semi-arid region. About 50,000 male calves and 25,000 heifers not needed as replacements, produced yearly in dairies and slaughtered soon after birth, could provide considerable additional beef.

About 25.8 million dozen eggs are produced locally and 20.6 million are imported yearly. About 56.7 million pounds of poultry are produced locally and 140.7 million are imported. Cost of production is high since feed is imported and expensive but many consumers are willing to pay higher prices for locally produced fresh eggs and poultry.

About 33.9 million pounds of pork are produced locally and 61.9 million pounds are imported fresh or frozen yearly. There are about 235,000 pigs, mostly in semi-commercial operations. Pigs are fed on imported concentrates, left-overs from restaurants and crop residues.

About 3 million pounds of fresh or frozen goat meat and 3 million pounds of rabbit meat are consumed yearly. Almost all these animals are raised in small numbers and either slaughtered on the farm or sold to individual buyers.

Forage from pastures should be used as the main feed for dairy, beef, goats and lambs and to some extent also for rabbits and pigs, since it is a far cheaper source of nutrients than imported feed. Cost of producing a pound of total digestible nutrients actually consumed by cattle is about 5.5 for forage from pastures compared to about 15¢ from imported concentrates.

Approximately 500,000 tons of concentrate feed are imported yearly. Grain crops, specially sorghum, could be grown on lands not suited to higher income crops or in rotation with others. Local by-products used for feed include residues from pharmaceutical companies and tuna canneries, molasses, pineapple skins, brewers by-products and sugarcane bagasse.

Village free roaming animal husbandry has no place on the Islands, and raising animals in cages or small enclosures is limited to pigs, rabbits and poultry. Free ranching is adapted to large farms in the semi-arid region and grazing under trees is generally not practiced. Cattle will continue to be raised in small numbers for milk and beef on the farm.

Manure can be used mixed with other ingredients to feed cattle or as a source of energy. Disposal is not a problem with grazing cattle but can be a hazard with large dairy, poultry and pig operations. Manure can be spread on pastures reducing fertilizer costs or disposed of in suitably constructed and managed ponds.

ASSESSMENT OF LIVESTOCK PRODUCTION TECHNOLOGIES IN U.S. AFFILIATED CARIBBEAN ISLANDS - PUERTO RICO

INTRODUCTION

Puerto Rico is located about 1,000 miles East-Southeast of Florida. It has an area of 3,435 square miles and a population of 3.3 million.

Rainfall ranges from 30 to 180 inches yearly. Mean annual temperatures vary from 21-26°C. Maximum daily temperatures rarely exceed 32°C with minimums rarely below 18°C (U.S. Weather Bureau, 1982).

There are approximately 270,000 acres of mechanizable lands with sufficient water from rainfall or irrigation for the production of a wide range of agricultural products (Vicente-Chandler, 1978). Over 100,000 acres of these lands are in pastures, primarily for dairies. About 70,000 are in sugarcane and the remainder in such crops as vegetables, pineapples, rice, pigeon peas, plantains, bananas and root crops.

There are approximately 600,000 acres of partially mechanizable lands in the humid region with deep, porous soils and sufficient rainfall for the production of most perennial crops and an additional 300,000 acres of moderately deep soils well adapted to commercial pine forests which could produce all the wood products of this type which are now imported. An additional million acres are too steep, too shallow, too rocky or dry for economic production of forests or agricultural products and should remain in native forests for wildlife, recreation and watershed protection.

The 600,000 acres of agricultural lands in the humid mountain region could supply the local market for coffee (30,000 acres), plantains (15,000), bananas (6,000) and citrus (5,000 acres) (Vicente-Chandler, 1978), having over 500,000 acres which could be used for pastures for beef and meat production.

Net income from the production of Honduras Pine is considerably higher than for beef production from cow-calf operations but the need for waiting 20 years before profiting from the investment and possible losses due to hurricanes make this alternative less attractive for most farmers. Commercial forests require incentives to reduce the initial investment and consequently, the high cost of interests over a 20-year period.

Well managed tropical pastures are an excellent means of protecting soils against erosion (Vicente-Chandler, 1983) as are well managed forests. The relative merits of pastures and woodlands for water conservation under tropical conditions are not well established but well managed forests are probably superior in this sense.

Over the past 30 years tobacco production has disappeared, sugarcane production has been reduced by 90%, coffee production remains fairly stable supplying about 2/3 of the local market. Production of food crops decreased but production of plantains, bananas, fruits and tropical root crops has remained fairly stable during the past 10 years.

Production of animal products, however, has increased tremendously over this period (Anonymous, 1983). Yearly milk production has increased from 225 to 374 million liters, pork from 17 to 33.9 million pounds, poultry from 13.5 to 56.7 million pounds, eggs from 9.8 to 25.8 million dozen, and beef from 19 to 45.7 million pounds. These livestock products have a farm value of $321 million yearly compared to a total value for all agricultural products of $580 million.

Milk Production

About 374 million liters of fresh milk are produced yearly with a farm value of $154 million, 6 million liters of UHT milk are imported, and the equivalent of 150 million liters are imported dry or condensed. Increasing quantities of UHT milk, which can be stored without refrigeration, are being imported and some is produced locally.

There are about 600 first class dairies with approximately 130,000 acres in pastures and 10,000 in grasses for cutting. The average size of the dairy farms is 250 acres. There are about 110,000 cows averaging 12.4 liters daily, fertility problems are common, mastitis is widespread, and bacterial counts in the milk are often high. Excessive quantities of expensive, imported concentrates (16-18 percent protein) are used, an average of over 1.5 pounds/liter of milk (320,000 tons yearly) at a cost of 19 cents/liter with a farm price of 49 cents.

On the other hand, experiments and large scale tests on private farms (Caro et al., 1972(c), 1976(b) have shown that the first 10 liters of daily milk production can be produced without concentrates if cows are grazed on well-fertilized, intensively-managed tropical grass pastures with additional production supplemented at the rate of 1-1.5 pounds of concentrates/liter depending on level of milk production.

There are hundreds of thousands of acres on moderate slopes in the humid mountain region which, if planted to improved grasses and well-fertilized, can carry one milk cow/acre throughout the year. Pastures help conserve steep soils, are drought tolerant, and little mechanization is required since cows graze even very steep lands and fertilizer can be applied with broad based tractors or by air.

There is very little information on the effects of increased fertilization of pastures on moderate slopes in the humid mountain region on surface and ground water quality. However, fast growing tropical grasses recover about 50% of the applied nitrogen, (Vicente-Chandler, 1974) similar to the recovery under temperate conditions, the soils are very deep and porous with intakes of 2 inches or more of water hourly under grass cover (Vicente-Chandler, 1984) and the acuifers in this region are generally below 100 feet. Normal levels of fertilization if put on in several applications yearly, probably will not seriously affect ground water supplies in the mountain region.

It is essential to improve efficiency in milk production, improve quality control, establish effective systems for disposing of manure, raise all dairy replacements locally and base production on increased acreages of well-managed grass pastures. The relatively low reproduction rate of dairy cows is largely the result of poor management of the herd including feeding, disease control and care of the animals. Artificial insemination is widely used and the genetic capability of the animals is superior to the level of management used.

Ticks, which were erradicated in the 1940's, are now a major problem over most of the Island, causing serious losses in weight, and transmitting Anaplasmosis, which can cause serious illness and death of cattle.

Production must be limited to the local market for fresh milk, which is protected by the high cost of imports. Employment can be maintained at about 5,000. The alternative is continually rising prices and increased imports for UHT milk.

Assuming that it will take 2 acres to feed a milk cow producing 3,000 liters yearly and to raise replacement heifers, the local demand for fresh milk could be supplied from 250,000 acres of intensively managed heavily fertilized pastures which should preferably be located in the mountain region. Lands in this area have few alternative uses, pastures are soil conserving, dairy operations require little mechanization since cows will harvest the forage by grazing and fertilizers can be applied with appropriate tractors or aerially. Furthermore, land is cheaper than in the coastal areas and the climate is more favorable for Holsteins, which comprise almost all the dairy cows on the Island.

Research (Vicente-Chandler et al., 1983) has shown that cost per liter of producing milk with cows having a modest production capacity and fed exclusively on grass pastures in the mountain region is only slightly higher than for higher priced, high yielding cows fed on such pastures supplemented with concentrates. Therefore, net farm income can be as effectively increased by increasing number of cows and acreage in pastures as by increasing quality of the cows and feeding more concentrates. In terms of the Island's economy the former alternative is obviously to be preferred in view of the large acreage of land suited to forage production and with few alternative uses and the fact that all concentrates are imported at a high cost.

Furthermore, every effort should be made to expand the dairy industry in the hilly mountain region and, insofar as possible, to transfer those now located on mechanizable lands to this region.

The Puerto Rico Government should provide cash incentives for planting improved pastures in the humid hill lands and grants of fertilizer for such pastures in order to decrease imports of concentrates and help conserve soil and water in this region and should regulate the industry to increase milk quality.

Beef Production

About 45.7 million pounds of beef were produced locally in FY 1983-84 with a farm value of over $40 million and 73.4 million pounds were imported fresh or frozen, about 26.4 million from the United States and 47 million from foreign countries. About 40% of the local beef comes from the dairy industry and another substantial portion from small farmers which graze a few head in their or neighboring farms or along roadsides. The remainder comes from range type operations in the semi-arid region. There are about 380,000 head of cattle raised for beef production.

About 50,000 male calves and 25,000 heifers not needed as replacements are produced yearly in dairies and almost all are slaughtered soon after birth. If 50,000 calves were grown to 800 pounds in 50,000 acres they would produce 20 million pounds of beef compared to 3 million when slaughtered at birth.

Over 1,000 pounds of gain in liveweight can be produced per acre yearly with intensively managed, well fertilized grass pastures in the humid mountain region (Caro-Costas et al., 1961, 1972(a), 1972(b), 1976(c), 1980, Vicente-Chandler et al., 1974, 1983).

Beef production should be limited to farms or areas of farms not suited to more profitable crops, since it creates few jobs and provides a low income. Only a modest increase in beef production for the local market is foreseen with employment of about 2,500. Disposal of manure is not a problem since practically all beef cattle are raised exclusively on pastures.

Local Government incentives should be provided for raising dairy calves and using culled cows to raise two calves each, for planting grasses on hill lands and for control of diseases, parasites and ticks and for building watering facilities.

The local beef industry faces very strong competition from imports originating in Central America where both land and labor are cheap. A similar situation is faced by U.S. beef farmers but the situation is less serious since cattle can be finished on cheap grain and there is an excellent market for quality cattle finished on grain.

Use of oxen as draft animals is limited to small farmers in the mountain region who cannot afford to pay for the investment in farm machinery. Altho oxen cost $2,000/yoke, there is very little depreciation and most animals are eventually eaten and they do not require expensive repairs or spare parts.

Poultry Production

About 25.8 million dozen eggs were produced locally in FY 83-84 and 20.6 million were imported. About 56.7 million pounds of poultry were produced locally in FY 83-84 and 140.7 million were imported. Approximately 150,000 tons of poultry feed were used mixed locally from imported ingredients. Almost all eggs and poultry are produced in vertically integrated operations and with facilities similar to those on the Mainland. Retail prices, however, exceed those of imported eggs and poultry.

Although local production is generally less efficient and feed is expensive it is theoretically possible to locally produce eggs at competitive prices since excellent breeds and techniques are available, the cost of imported feed can be decreased somewhat by more local competition among feed mills, investment in facilities is relatively low due to the benign climate, and the cost of importing eggs and poultry is high.

Poultry production has relatively little economic impact on the Island since more than two thirds of production costs is for imported materials and efficient operations are not labor intensive. It seems logical, therefore, to increase production only to the extent of satisfying the market willing to pay higher prices for local products. Such production would employ about 1,000 persons and requires protection against occasional "dumping" of Mainland products at prices below production costs.

About 8 million dozen eggs are produced by small farmers in family-type operations throughout the Island, particularly in the mountain region. Commercial units are centralized and located near the processing facilities and feed distribution centers.

There has recently been a considerable increase in thelarchy among Puerto Rican children and a study is underway to determine whether there is relation between this increase and consumption of poultry or beef, both imported and locally produced. No final determination has yet been made.

Pig Production

Approximately 33.9 million pounds of pork valued at $31 million were produced locally in FY 83-84, 61.9 million pounds were imported fresh or frozen and 106 million as processed products. There are about 35,000 pigs in commercial farms and about 200,000 in non-commercial operations (less than 10 sows or 50 piglets) and two thirds of the pigs are slaughtered on the farm. Approximately 40,000 tons of pig feed are produced from imported ingredients yearly, mostly for the commercial operations. Many of these hogs are fed on left-overs from restaurants and on crop residues.

There is a good local market for fresh pork from pigs weighing about 120 pounds to be used mostly for roasting. Imported pork is usually from animals weighing 200 pounds or more. A new nucleous of commercial producers is starting to produce, process and market larger animals for the local fresh pork market. As with poultry, local production theoretically could be competitive with imports.

Since production is based largely on imported feeds, no particular efforts should be made to increase production beyond the demand for fresh pork except for taking action to prevent dumping. Commercial production of lower fat, good quality pork should be increased using the most modern techniques. Pigs should also continue to be produced on rather small farms throughout the Island using as much slops from restaurants and local by-products as possible, including crop residues. About 1,000 persons can be employed in such an industry.

There is no precise information available on the efficiency and cost of producing pigs on imported concentrates vs. feeding food scrap on small farms. However, there is little doubt that the latter is more profitable if the cost of transportation required to collect the scraps is low and the farmer does his own driving.

Goats and Rabbits

There are no reliable statistics on the goat or rabbit population of Puerto Rico. Less than 3 million pounds of fresh or frozen goat meat are consumed yearly and probably about 3 million pounds of rabbit meat.

These animals are almost all raised in small numbers and are slaughtered on the farms or sold to individual buyers who slaughter and consume them.

Rabbits are fed on cut forage and concentrates (about 9,000 tons of rabbit feed are imported yearly). Goats are fed on forage and farm by-products and wastes.

There are 3 commercial-size operations raising goats for meat and one modern dairy produces goat milk for which there is an excellent local market, especially among children allergic to cows' milk. The milk goats are fed on roughage and concentrates. Employment in raising goats and rabbits could total several hundred persons.

Local Feed Sources

All the forage both from grazing pastures and from cut grasses can be produced locally as can the required hay. The latter should be produced in commercial operations on mechanized irrigated lands in the semi-arid south coast to facilitate sun drying and production of high quality roughage. Cost per pound of total digestibility nutrients from locally produced forage is about 5.5¢ compared to about 15¢ for total digestibility nutrients from concentrate feeds.

Some local by-products which can be used for livestock feed include residues from pharmaceutical companies and from the tuna canning plants, molasses as well as pineapple skins and brewers by-products and sugarcane bagasse (Randel, 1966). However, only a limited quantity of such products are available and could probably not substitute for more than 10% of imported feed.

Almost all the ingredients for the approximately 500,000 tons of concentrate feed used yearly for cattle, pigs and poultry used locally are imported mostly from the United States Mainland, none of the main ingredients (corn, oats, soybeans, wheat bran, cottonseed meal) are produced locally. Grain crops produce a low income, create few jobs and face strong competition from imports and should therefore be limited to areas with no better alternative uses or in rotation with higher income crops.

Grain crops, especially sorghum could, however, be grown on about 40,000 acres not suited to higher income crops or in rotation with vegetables during the off season, or with rice. Yields of over 5,000 pounds of grain sorghum or corn have been obtained per acre with two crops produced yearly. It is also possible to produce 2,000 pounds of soybeans per acre with irrigation but this crop requires processing facilities not now available. Grain is sold locally at about 2.5 cents more/pound than in the Mainland, due to shipping costs.

FORAGE FOR LIVESTOCK PRODUCTION

The year-round growing weather, high and fairly well-distributed rainfall, abundance of land with no other agricultural use and lack of locally produced concentrates indicates that increased milk, beef and goat production must be based on tropical forages.

There is still no tropical legume which has been successfully grown on a commercial scale in mixtures with grasses in the humid tropics of Latin America.

Although the literature indicates that tropical grasses are low in quality, research in Puerto Rico has conclusively shown that not only are they higher yielding than temperate region grasses but are just as high in quality if properly managed (Vicente-Chandler et al., 1983, Arroyo-Aguilũ et al., 1975).

Due to their high yield capacity, tropical grasses can remove very large quantities of nutrients from the soil (Table 1) Vicente-Chandler et al., 1974). Also, most soils of the humid tropics have a low capability for providing nutrients. For example, Figure 1 (Abruña et al., 1976) shows that altho most soils of Puerto Rico can initially provide fairly large quantities of potassium to grasses, these reserves are depleted during the first year or so after which most soils provide less than 100 kg of potassium/ha/year. As a result, tropical grasses respond very strongly to fertilization, particularly with nitrogen as shown in Figure 2 (Vicente-Chandler et al., 1974, 1983).

The grasses are also strongly affected by harvest interval with yields increasing (Figure 3) and digestibility decreasing with increasing harvest interval or age (Figure 4).

Grazing rather than the cut feeding, decreases yields of forage actually consumed by the animals to about half as a result of a shorter harvest interval, losses caused by trampling and selectivity of the animals grazing pastures (Figure 5). On the other hand, forage consumed by grazing animals has a higher protein content as shown in this figure. The high quality of forage ingested by animals grazing intensively-managed pastures is shown in Table 2 (Caro-Costas et al., 1976).

Under grazing management, grasses require heavy fertilization in order to maximize yields, an important factor in Puerto Rico where land is scarce and expensive and must therefore be used intensively. Table 3 (Caro-Costas and Vicente-Chandler, 1972, 1961) shows that increasing fertilization from 675 to 2,025 kg/ha yearly increased gains in weight from 638 to 1,201 kg/ha yearly and increased the carrying capacity of the pastures from 3.5 to 5.5 animals/ha. Protein content of the forage consumed by the cattle was also increased from 8.1 to 15.9% by this increase in fertilization. Table 4 shows similar results with Pangola grass pastures. Figure 6 shows that total digestibility nutrients ingested by grazing animals increases with fertilizer rates up to at least 2,000 kg/ha/year (Vicente-Chandler et al., 1983).

The high productivity of intensively managed grass pastures in the humid mountain region of Puerto Rico in terms of animal gains are shown in Tables 5 and 6 (Caro-Costas et al., 1976, 1972, 1980). Para (*Brachiaria purpurascens* (Raddi) and molasses grasses (*Melinis minutiflora*) were inferior in productivity to Guinea (*Panicum maximum* Jacq.), Napier (*Pennisetum purpureum* Schum.), Pangola (*Digitaria decumbens* Stant.) and Star (*Cynodon nlemfuensis*).

A comparison of the data in Tables 5 and 6 with those in Table 7, showing productivity of well-fertilized irrigated pastures on the South Coast, indicates that only about 20% higher yields are obtained on these excellent lands with many other agricultural uses.

The following tabulation shows average milk production per lactation for Holstein cows fed only on steep, well-managed grass pastures for five consecutive lactations (Caro-Costas and Vicente-Chandler, 1976).

Lactation	Liters of milk/ cow/lactation
1 (first calf heifers, poorly developed)	2,044
2	3,696
3	3,897
4	4,058
5	4,817
Average	3,702

Cows producing an average of 12 liters of milk daily can obviously be fed on such pastures with no concentrate feed.

Table 8 shows that with higher yielding cows on good pastures, concentrate feeding can be reduced from current practice of over 0.7 kg per liter to 1 kg per 6 liters of milk without affecting milk production while greatly decreasing cost of milk production (Caro-Costas et al., 1972).

ECONOMICS OF CATTLE PRODUCTION

Table 9 shows that cost of producing a kg of total digestible nutrients (TDN) actually consumed by cattle is about 17¢ for cut forage and about 12¢ for forage from pastures compared to about 32¢ per kg of TDN from imported concentrate feeds (Vicente-Chandler et al., 1983). Cost per ton of dry forage consumed by cattle is about $80 for cut forage compared to $66 for pastures but a hectare of intensively managed pastures produces only about 15 tons of dry forage ingested by cattle compared to 24 tons for cut forage.

Table 10 shows that a dairy with cows fed exclusively on intensively managed grass pastures in the humid mountain region can be a profitable operation with a net income of about $69,000 yearly and a per liter cost of 37.6¢ compared to a farm price of 48¢ (Vicente-Chandler et al., 1983).

Table 11 shows that, as would be expected, the net income of a dairy of a given size can be sharply increased by using higher yielding cows and feeding concentrates in proportion to increased milk production. In all cases the first 10 liters of milk are produced without concentrate feed with additional production supplemented with concentrates. It should be noted, however, that costs per liter of milk decreased only slightly from 32.3 to 29.8¢ with increasing milk production capacity of the cows and increased use of concentrates. This shows that profits can be similarly increased either by using higher yielding, more expensive cows and more concentrates or by increasing acreage in pastures and number of cows with a lower capacity for producing milk.

Table 12 shows that growing out young cattle for slaughter produces a small negative net income if all costs are considered but returns a modest cash income. Raising dairy replacement heifers can be profitable both in terms of net and cash income.

On the other hand, cow-calf operations with intensively managed pastures in the humid region are not profitable (Table 13). However, such farms can be modestly profitable on a cash basis in the semi-arid regions where no fertilizer is applied and large areas of low cost land are available.

ASSESSMENT OF LIVESTOCK PRODUCTION TECHNOLOGIES IN U.S. AFFILIATED CARIBBEAN ISLANDS - U.S. VIRGIN ISLANDS

INTRODUCTION

The U.S. Virgin Islands are located about 50 miles east of Puerto Rico, between 17°30' to 18°30' north latitude and 65°15' to 60°40' west longitude. The major islands are St. Thomas with 19,784 acres, St. Croix with 54,563 acres, and St. John with 12,835 acres. Population of the three islands is about 120,000.

Yearly rainfall varies from a low of 20 inches in the eastern part of St. Croix to between 50-60 inches and temperature ranges from 28°-32°. (Anonymous, 1980). Average annual rainfall is about 43 inches, but it is highly variable from place to place on the islands and from month to month. There is a usually wet season from August to November but there is not sufficient moisture to maintain continued plant growth during the remainder of the year. Lack of available water is the main physical factor limiting livestock production in the Virgin Islands.

Milk Production

Approximately 3 million liters of fluid milk are produced yearly and 400,000 are imported. Milk is the main agricultural industry of the Islands (Stammer, 1974) protected by the high cost of importing fresh milk. There are 5 commercial dairies in the Virgin Islands with about 600 milk cows on some 5,000 acres of improved pastures.

In order to reduce costs, milk production should be based as much as possible on intensively managed and fertilized pastures of Guinea or Buffel grasses supplemented with hay, with higher yielding cows fed limited quantities of expensive concentrates, all of which are imported. About 2,000 tons of livestock feeds, mixed in Puerto Rico from imported ingredients, are imported yearly, mostly for dairies.

Grazing during the rainy season must be complemented by feeding silage or hay during the dry season, generally from January through March. With proper care, Buffel, Pangola, Guinea and other grasses can be made into hay. Sorghum silage has a higher nutritive value and Sordan (sorghum x sudan grass) can yield 60 tons of green forage/acre yearly and several forage sorghum hybrids can yield over 40 tons but silos, machinery and trained personnel are needed to make good silage at a low cost and hay is therefore a preferred alternative.

Grain sorghum can also produce a seed and a ratoon crop with total yields of 4-6,000 pounds/acre. This crop could be grown on 12,000 acres of excellent soils (Anonymous, 1980) in St. Croix, but there is little machinery currently available locally for producing, harvesting and drying the grain.

Beef Production

About 700,000 pounds of beef and veal are produced yearly in the Virgin Islands and 4,300,000 are imported. There are about 4,000 head of beef cattle on 8,000 acres of improved pastures on 64 farms (Park and Park, 1974) and about 12,000 acres of unimproved grasslands.

Some land owners use beef production to reduce the cost of holding land pending conversion to higher economic uses. Returns can cover out-of-pocket costs and give a return to management but cannot pay for investment in the land which is very expensive.

Production is mostly of medium quality beef animals for relatively low income consumers. The tourism industry relies mostly on imported high quality beef.

The beef industry should be concentrated on areas of higher rainfall where improved grass species such as Guinea, Star and Buffel can be planted, and properly managed. Trench silos should be built to preserve the grasses as silage for use during the dry season. Sorghum x grass hybrids should be planted for silage since they are high yielding.

There is an excellent beef type breed of cattle on St. Croix--the Senepol--developed in the early 1900's. It is a medium size breed with good beef characteristics.

Pig Production

About 163,000 pounds of pork are produced yearly and 1,842,000 pounds are imported.

There are approximately 1,000 hogs and a strong demand for 40-50 pound pigs for roasting especially near Christmas with some demand for 120-pound animals throughout the year (Jensen and Park, 1974).

The main limitation to increased pig production is the high cost of concentrates, all of which are imported, competition from imports from the U.S. Mainland, little experience in scientific production methods, and a lack of modern marketing facilities. Since these products are based on imported feed, which accounts for more than 2/3 of production costs, they would make only a limited contribution to the economy of the Virgin Islands. Hogs can best be produced in family-size operations using agricultural by-products and food left-overs.

Goats and Sheep

About 20,365 pounds of goat, lamb and mutton are produced yearly and 593,000 pounds imported. There are about 3,000 sheep and 6,000 goats. Small flocks of sheep and goats prevail in St. Croix (McKenzie, 1967). It is a part-time actitivy to supplement off-farm income and should be encouraged by incentives to improve the quality of the animals and access to better grazing lands (Park and Park, 1974). Production should be increased sharply since these animals do not require imported feed and can thrive on local forages.

Poultry

About 10,000 pounds of poultry are produced and 9,100,000 are imported, 140,000 dozen of eggs are produced and 1,430,000 are imported.

There is a large local market for eggs and poultry. The cost of production is high because all feed is imported. Local feed sources should be developed, mainly grain sorghum. Also the latest poultry crosses and improved management practices must be introduced so as to increase efficiency. Short courses in the different areas of livestock production should be taught to interested young people and incentives given to farmers to help them improve their grazing lands and water supply, buy the needed equipment, etc.

CONSTRAINTS AND OPPORTUNITIES

Milk and Beef Production

In Puerto Rico there is abundant land in the mountain region with few alternative uses available for grazing cattle for milk and meat production. These lands can produce high yields of pasture which protect the soil against erosion, livestock operations can be as efficient as on level lands since grazing cattle "harvest" their feed, fertilizer can be applied with broad-based tractors or by air and the climate in the mountain region is more favorable for the milk breeds.

On the other hand, milk cows are fed excessive quantities of expensive imported grain. Although it has been shown that little concentrates are required cows are grazed on intensively managed grass pastures (Caro et al., 1972 and 1976). The potential for producing grain for cattle feed is small since there is limited mechanizable land with many other higher producing alternatives and with higher labor requirements.

Although milk production can be highly profitable, beef cattle production, particularly cow-calf operations, provide low income and require little labor and should therefore be concentrated on the less productive lands.

Government action should be aimed at increasing the use of grass pastures in the feeding of milk cows in order to reduce production costs and decrease costly imports of grain.

It is estimated that through the proper use of grass pastures cost of producing milk can be decreased by about 8 cents per quart and imports (feed plus fertilizer for pastures) can be decreased by $38 million while increasing employment in the planting and fertilizing of such pastures (Vicente-Chandler, 1985).

In the Virgin Islands the marked dry season is a definite constraint to increased cattle production which can be ameliorated through the use of hay and or silage produced during the rainy season. However, considerable investment in equipment and facilities are required, particularly for silage production and storage.

The local Department of Agriculture could provide incentives for raising dairy calves (about 75,000 are slaughtered soonafter birth in Puerto Rico) as a by-product of the dairy industry to increase beef production without the cost of maintaining beef cows. Both the local and U.S. Departments of Agriculture could provide incentive payments for planting grasses as a soil protective measure on hill lands and fertilizer for increasing this protection and providing a source of feed for cattle. Possible congressional action might be to provide funds for these incentives from the food stamp program.

Another limiting factor to increased milk production is fertility problems with dairy cows. This problem can be solved by better management and health practices which require an intensive effort on the part of the Extension Service which should receive additional funds ear-marked for this purpose.

A massive educational program is also required to improve hygiene in dairies in order to reduce bacterial counts and antibiotics in the milk.

It is also essential that ticks be erradicated from the Islands as soon as possible. Ticks weaken cattle by removing blood and also transmit Anaplasmosis which can seriously affect production and can also cause death. Both federal and state funds are needed for a massive well coordinated program with a definite timetable for attaining tick erradication.

Competition from beef imports, especially from Central America where land and labor are cheap, is a serious constraint for the local beef industry.

Free ranching technologies will continue on large scale farms with few alternative uses in the semi-arid region, primarily for cow-calf operations and for raising young beef cattle. On a more limited scale, goats for meat production will also be raised under these conditions.

Grazing livestock under trees, with the exception of medium-size trees and brush on semiabandoned farms, is not practiced in Puerto Rico and is not likely to be unless commercial forests are established.

A considerable number of cattle will continue to be raised for the production of milk consumed on the farm and to sell for slaughter in rural areas. Many of these cattle are tethered on road sides or in abandoned farms or are grazed on such lands either free of charge or paying a small annual fee. There are several large operators who lease Government lands, both state and federal, for grazing livestock.

Practically all locally available feed materials with a potential for cattle feed are now being used.

The dairy industry will continue to be based almost exclusively on Holsteins which have shown their adaptability to a wide range of conditions if properly managed. In addition to producing more milk than other breeds, they are also capable of producing considerable beef and crosses with beef animals, particularly Brahmas, have been shown to make excellent gains in weight and produce beef of acceptable quality for market which prefers lean meat (Carlo et al., 1970, 1975). In addition, crosses of Brahmas with Charolais (Charbray), and to a limited degree with other breeds, will probably increase if a market develops for higher quality beef.

The main negative environmental impact of livestock is related to disposal of manure. Under grazing management impact is minimal except near supplies of drinking water and under shade trees where manure tends to be concentrated. Disposal of manure in dairies where cows are confined during prolonged milking periods can be a problem as is also the case with large pig or poultry operations. Manure can be spread on pastures reducing the need for fertilizer or can be disposed of in suitably constructed ponds.

Village free roaming animal husbandry has no place in modern Puerto Rico or the Virgin Islands. However, free roaming chickens will continue to be raised in rural areas.

A great deal of research has been conducted in Puerto Rico on the use of forages for beef and milk production, the use of concentrates for complementing these rations with higher quality animals as discussed previously and with regard to the use of local by-products as feed. Research on the control of diseases and parasites can generally be transferred from the U.S. Mainland or other countries but research to obtain registration is often needed as is research on the control of tropical parasites.

Pigs and Poultry

The limiting factor to increased production of pork, poultry and eggs is the high cost of imported feed which is much higher than can be justified by purchase price in the U.S. plus transportation. Increased competition between local producers of feed could decrease these costs appreciably. It also seems that the much wider feed conversion ratios obtained in the Island as compared to the U.S. may be due to inferior quality of feed as compared to similar feed in the U.S. Mainland. Some measures for quality control of feed should be implemented by the local and U.S. Departments of Agriculture.

Both poultry and pig products from U.S. Mainland are frequently dumped at prices below their cost of production seriously disrupting the market for local products. This problem can be ameliorated by providing a mechanism for rapidly applying the federal laws which prohibit interstate dumping at prices below production costs. Congressional action could be helpful in this respect.

Production systems for pig and poultry should be more vertically integrated with larger production units and increased use of technology which can be directly transferred from the U.S. since the same breeds, feeding and management procedures are used. Increased credit is required to attain this objective.

Possible congressional action might be to provide U.S. grain at low prices to increase pig and poultry production on the Islands.

Animal husbandry in cages or small enclosures will continue to be limited, as at present, to pigs, rabbits and poultry.

Rabbit raising could be expanded, as could production of goats, Guinea hens, ducks and turkeys.

Use of animal by-products, not now being used, is limited to manure. This is being used as a source of energy on one hog farm in Puerto Rico after being converted to methane. Poultry manure can be used mixed with other ingredients to feed cattle.

The technologies for producing eggs, poultry, hogs and rabbits used on the U.S. Mainland are transferable to conditions in Puerto Rico and the Virgin Islands.

On the other hand, a considerable effort is required to transfer tested technology to commercial operations with all livestock commodities. A system based on model farms and short training courses on these farms would seem to be the most effective method considering the excellent communications available on the Islands. Needsintegrated approach between Extension Service, government action programs and long term commitment by both. Also needs yearly training courses, mandatory if possible, for all dairy operators.

The recommended actions have no apparent negative constraints either social, political or environmental. The technological, physical, marketing and social factors have been discussed throughout this report and by Vicente-Chandler et al. (1985) and are not repeated here because they are generally applicable to agriculture in Puerto Rico.

BIBLIOGRAPHY

1. Anonymous, 1980. Soil Survey of the Virgin Islands - U.S. Soil Conservation Service.

2. Anonymous, 1982. U.S. Weather Bureau Report - Puerto Rico.

3. Anonymous, 1983. Facts and Figures on Puerto Rico's Agriculture - Department of Agriculture - Commonwealth of Puerto Rico, 1-93.

4. Abruña, F., Vicente-Chandler, J., Figarella, J. and Silva, S., 1976. Potassium supplying power of the major Ultisols and Oxisols of Puerto Rico, J. Agr. Univ. P.R., 55(1): 45-49.

5. Arroyo-Aguilú, J. A., Tessema, S., McDowell, R. E., Van Soest, P. J., Ramírez, A., and Randel, P. F., 1975. Chemical composition and in vitro digestibility of five heavily fertilized tropical grasses in Puerto Rico, J. Agr. Univ. P.R., 59(3): 186-98.

6. Carlo, I., Arcelay, C. L., Mendoza, R., Ramírez, W., and Cestero, H., 1970. Evaluación de datos obtenidos de toros y novillas procedentes del primer cruce entre toros de raza para carne con vacas lecheras desechadas, Est. Exp. Agr. Univ. P.R. Bol. 225.

7. Carlo, I., Mendoza, R., and Vélez, J., 1972. Evaluation of different feeding systems in beef cattle production, J. Agr. Univ. P.R., 56(4): 327-36.

8. Caro-Costas, R., 1980. Weight gains of cows fed on five grass pastures intensively managed in the humid hill region of Puerto Rico, J. Agr. Univ. P.R., 64(1): 43-6.

9. Caro-Costas, R., Abruña, F., and Vicente-Chandler, J., 1972a. Comparison of heavily fertilized Pangola and Star grass pastures in terms of beef production and carrying capacity in the humid mountain region of Puerto Rico, J. Agr. Univ. P.R., 56(2): 104-10.

10. Caro-Costas, R., Abruña, F., and Vicente-Chandler, J., 1976a. Effect of three levels of fertilization on the productivity of Star grass pastures growing on a steep Ultisol in the humid mountain region of Puerto Rico, J. Agr. Univ. P.R., 60(2): 172-78.

11. Caro-Costas, R. and Vicente-Chandler, J., 1961. Effect of fertilization on carrying capacity and beef production by Napier grass pastures, Agron. J. 53(3): 204-5.

12. Caro-Costas, R. and Vicente-Chandler, J., 1972b. Effect of heavy rate of fertilization on beef production carrying capacity of Napier grass pastures over 5 consecutive years of grazing under humid tropical conditions, J. Agr. Univ. P.R., 56(3): 223-27.

13. Caro-Costas, R. and Vicente-Chandler, J., 1976b. Milk production by Holstein cows fed only on grass during five consecutive lactations, J. Agr. Univ. P.R., 60(3): 436-38.

&c

14. Caro-Costas, R., Vicente-Chandler, J., and Abruña, F., 1972. Effect of four levels of concentrate feeding on milk production by Holstein cows grazing intensively managed tropical grass pastures, J. Agr. Univ. P.R., 56(2): 99-103.

15. Jensen, F. and Park, R. L., 1974. Profitability of Hog Production in the U.S. Virgin Islands, V.I. Exp. Sta. Report 6, 1-14.

16. McKenzie, D., 1967. Goat Husbandry, Second Edition, Publ. Latimer Tread Ltd. 1-368.

17. Park, W. and Park, R. L., 1974. Goat and Sheep Enterprises in the U.S. Virgin Islands, V.I. Exp. Sta. Report 7, 1-12.

18. Park, W. and Park, R. L., 1974. Beef Production in the U.S. Virgin Islands.

19. Peterson, R. S., Woodhouse, W. W. and Lucas, H. L., 1956. The distribution of excreta by freely grazing cattle and its effect on pasture fertility. II. Effect of returned excreta on the residual concentration of some fertilizer elements. Agro. J. 48(10): 444-8.

20. Randel, P. F., 1966. Feeding lactating dairy cows concentrates and sugar cane bagasse as compared with a conventional ration, J. Agr. Univ. P.R., 50(4): 255-69.

21. Stammer, R., 1974. Livestock production in the U.S. Virgin Islands, V.I. Exp. Sta. Report 8, 1-30.

22. Vicente-Chandler, J., 1978. Conceptos, Planes y Programa para una Agricultura Moderna en Puerto Rico. P.R. Department of Agriculture.

23. Vicente-Chandler, J., Caro-Costas, R., Abruña, F. y Silva, S., 1983. Producción y Utilización Intensiva de las Forrajeras en Puerto Rico, Agri. Exp. Sta. Univ. P.R. Bull. 271.

24. Vicente-Chandler, J., Caro-Costas, R., Pearson, R. W., Abruña, F., Figarella, J., and Silva, S., 1974. The Intensive Management of Tropical Forages in Puerto Rico, Agri. Exp. Sta. Univ. P.R. Bull. 187.

25. Vicente-Chandler, J., 1985. Una Nueva Agricultura para Puerto Rico - Año 2000.

Table 1 - Withdrawal of Nutrients in Forage of Grasses Harvested by Cutting at Orocovis, Puerto Rico 1/

Grass	Yields of dry forage kg/ha/yr	Nutrients removed in forage kg/ha/yearly Nitrogen	Phosphorus	Potassium	Calcium	Magnesium
Napier	28,200	338	72	564	108	71
Guinea	25,800	323	49	407	167	111
Pangola	26,500	335	53	400	122	75
Pará	26,900	344	48	429	129	88
Congo	33,500	342	55	450	153	78
Star	28,300	388	65	469	151	54
Molasses	14,800	232	36	233	63	49
Average	26,288	328	54	422	128	75

1/ Fertilized with 450 kg of nitrogen, 73 of phosphorus, and 450 of potassium/ha yearly in six equal applications. Soil limed to pH 6.0 and grasses cut every 60 days.

Table 2. - Effect of season of the year on percent dry weight composition of Star grass samples obtained by plucking so as to simulate grazing (3,140 kg of 15-5-10 applied/ha yearly).

Month	Apparent 1/ digestibility of dry matter	Lignin	Silica	Crude protein	Phos-phorus	Calcium
December	67	5.0	2.0	19.6	0.25	0.47
January	72	3.9	1.4	26.3	.26	.44
February	69	4.5	1.6	23.3	.22	.41
March	58	5.8	2.6	17.4	.17	.35
April	69	4.0	1.5	24.1	.22	.40
May	68	4.2	1.6	22.7	.25	.38
June	66	4.0	1.3	18.9	.26	.39
July	70	3.9	1.1	23.3	.26	.38
August	72	3.9	0.9	25.9	.21	.42
September	72	3.5	1.0	22.1	.17	.35
October	70	4.0	1.6	24.3	.17	.31
Average	68.5	4.2	1.5	22.5	0.22	0.39

1/ Substract 13 to obtain approximate real "in vivo" digestibility.

Table 3 - Effect of three fertilizer levels on the productivity of steep Napier grass grazed by young cattle over a 2-year period at Orocovis.

15-5-10 fertilizer applied (kg/ha yearly)	Gains in weight (kg/ha yearly)	Carrying capacity (number of 270-kg animals/ha) 1/	Dry forage consumed by cattle 2/ (kg/ha yearly)	T.D.N. consumed by cattle 3/ (percent)	Digestibility of dry forage consumed by cattle 4/ (percent)	Protein content of forage consumed by cattle (percent)
675	638 b	3.5 b	9,970 b	4,820 c	48	8.1b
2,025	1,201 a	5.5 a	15,010 a	7,500 a	50	15.9 a
3,375	1,333 a	6.3 a	15,230 a	9,070 a	59	17.6 a

1/ One 270 kg animal making normal gains requires 3.9 kg of T.D.N. daily equivalent to 1,400 kg yearly.
2/ From differences in forage harvested from paired strips cut before and after grazing each pastures.
3/ Calculated from body weights, days of grazing, and gain in weight following recommendations of the Pasture Research Committee (1,2).
4/ $\frac{\text{T.D.N. consumed}}{\text{dry forage consumed}} \times 100$

Table 4 - Effect of four levels of fertilization on the productivity of Pangola grass pasture on steep slopes near Orocovis over 2 consecutive years of grazing.

15-5-10 fertilizer applied kg/ha/year	Gains in weight kg/ha/year	T.D.N. consumed by cattle kg/ha/year 1/	Carrying capacity 2/ number of 270 kg animals/ha	Minimum head carried number/ha
450	398 b	2,630 b	2.0 b	1.25
1,350	633 b	4,558 b	3.25 b	2.5
2,700	976 a	6,983 a	5.0 a	3.75
3,800	1,054 a	8,254 a	6.0 a	5.0

1/ Calculated from body weight, days of grazing and gains in weight following recommendations of the Pasture Research Committee (1,2).

2/ One 270-kg animal making normal gains requires 3.9 kg of T.D.N. daily or 1,400 kg yearly.

Table 5 - Productivity of well-fertilized pastures of five grasses on steep slopes over a 4-year period at Orocovis

Grass	Gains in weight kg/ha/yr	Average daily gains per head kg	Total digestible nutrients 1/ consumed kg/ha/yr	Carrying capacity number of 270 kg animals/ha	Minimum head carried number/ha
Guinea	1,319 a	0.60	8,941 a	6.5 a	5.0
Napier	1,110 a	0.60	8,140 a	5.8 a	5.0
Pangola	1,124 a	0.60	8,316 a	6.0 a	5.0
Para	781 b	0.50	6,434 b	4.5 b	3.25
Molasses	644 b	0.45	4,838 b	3.5 b	3.25

1/ Calculated from body weights, days of grazing, and gains in weight following recommendations of the Pasture Research Committee (1,2).

2/ One 270-kg animal making normal gains requires 3.9 kg of T.D.N. daily equivalent to 1,400 kg yearly.

Table 6 - Productivity of intensively managed pastures of Congo, Star, and Pangola grasses at Orocovis

Grass	Gains in weight	Average daily gains/ head	Total digestible nutrients 1/ consumed	Carrying capacity 2/	Dry forage consumed	Apparent digestibility of forage consumed 3/
	kg/ha/yr	(kg)	kg/ha/yr	Number of 270 kg animals per ha	kg/ha/yr	percent
Star	1,427 a	0.59 a	10,089 a	7.2 a	17,969 a	56.2 a
Congo	946 b	0.47 b	7,521 b	5.4 b	13,415 b	56.1 a
Pangola	1,023 b	0.54 a	7,836 b	5.6 b	15,329 b	51.1 a

1/ Calculated from body weights, days of grazing, and gains in weight following recommendation of Pasture Committee (1

2/ One 270 kg animal making normal gains requieres 3.9 kg of T.D.N. daily equivalent to 1,400 kg yearly.

3/ $\frac{\text{T.D.N. consumed}}{\text{Dry forage consumed}} \times 100$

Table 7 - Productivity of well fertilized 1/ pastures of three grasses under irrigation in the south coast of Puerto Rico

Grass	Gains in weight	Total digestible nutrients 2/	Carrying capacity 3/	Daily gains in weight/ head 4/
	kg/ha yearly	kg/ha yearly	270 kg head/ha	kg.
Napier	1,460 a	10,250 a	7.3 a	0.60 a
Guinea	1,420 a	10,730 a	7.7 a	0.55 a
Pangola	1,170 b	8,600 b	6.3 b	0.50 a

1/ Three tons of 14-4-10/ha yearly.

2/ Calculated from body weights, days of grazing and gains in weight following recommendations of the Pasture Research Committee (1,2).

3/ One 270-kg animal making normal gains require 3.9 kg of T.D.N. daily equivalent to 1,400 kg yearly.

4/ For "tester" cattle remaining on pasture throughout the course of the experiment.

Table 8 - Effect of four levels of concentrate feeding on milk produced by Holstein cows grazing heavily fertilized, intensively managed tropical grass pastures 1/

One kg of 20percent protein concentrate feed per	Average production per cow per lactation	Average length of lactation	Average daily production per cow	Cost of concentrates per liter of milk 2/	Average butterfat content of milk
	Liters	Days	Liters	Cents	Percent
2 liters of milk	4,422 a	268 a	16.5 a	11.0	3.0
4 liters of milk	4,900 a	280 a	17.5 a	5.5	3.0
6 liters of milk	4,949 a	288 a	17.2 a	3.7	3.5
8 liters of milk	3,385 b	242 b	14.0 b	2.8	3.3

1/ All values are averages for 12 cow in each treatment.

2/ With concentrates at 22 cents/kg.

Table 9 - Approximate costs of producing forage with intensive management in the humid region of Puerto Rico

Item	Cut grass Dollars/ha		Grass pastures Dollars/ha
Interest (10%) on investment in land and grassland establishment 1/	$ 350.00		$ 250.00
Taxes, labor insurance, farm upkeep etc.	150.00		100.00
Fertilizer ($200/Ton.) (4T/ha yearly)	800.00	(2T/ha yearly)	400.00
Limestone ($10/Ton.) (4T/ha yearly)	40.00	(2T/ha yearly)	20.00
Labor 2/, (Fertilization, liming, weeding, fence repair, etc.)	120.00		200.00
Depreciation of pastures 3/	25.00		25.00
Harvesting, chopping, and transportation (labor and equipment) 4/ (150 T)	450.00		--
Total Cost/ha	1,935.00		995.00
Cost per ton of green forage (150 ton of green forage = 39 tons of dry forage or 35 tons of hay)	$ 12.9		
Cost per ton of dry forage consumed by cattle 5/ (24T)	$ 80.62	(15T)	$ 66.30
Cost per kg of T.D.N. (cents) (45 digestibility)	17.01¢	(55 digestibility)	12.06¢

1/ $3,000/ha for mechanizable land used for cut grass and $2,000/ha for pasture land in the hill and mountain region + $500/ha to establish the pastures.

2/ Wage: $3.50/hr.

3/ Cost of establishing one ha of grass = $500 depreciated over 20 years.

4/ Using forage harvester and chopper with trailer. Assumes sufficient land to keep equipment working efficiently.

5/ Assuming 20 percent wastage in feeding cut grass yield from pasture based on actual consumption by grazing cattle as per data given elsewhere in this publication.

Table 10 - Annual costs and profit in a 65 ha dairy with an average of 145 cows in milk fed exclusively on well managed tropical grass pastures.

Labor (At 3.50/hour)		
Milking and care of herd	12,108 hours	$ 42,378
Pasture fertilization, liming and fences repair	5,544 hours	19,404
Miscellaneous	2,603 hours	9,110
Total Labor	19,715 hours	$ 70,882
Materials		
Fertilizer	185 T at $200	$ 37,000
Lime	220 T at $9	1,980
Medicines		3,940
Miscellaneous		3,015
Total Materials		$ 45,935
Other Expenses		
Social Security, State insurance fund, taxes, insurance, etc.		$13,640
Artificial insemination and veterinary services		4,400
Electricity and water		6,020
Purchase of replacement heifers (29 x $800)		23,200
Use of vehicles and miscellaneous costs		2,600
Interest on investment (10% of $315,000)		31,500
Interest on operating loans		5,380
Depreciation of building, equipment and pastures		5,330
Total Other Expenses		$ 92,070
Total Expenses		$208,887
Income		
Sale of milk (555,500 lts. x 48c/)		$266,640
Sale of calves (110 x $40)		4,800
Sale of cows 22 ($300)		6,600
Total Income		$278,040
Net Income		69,153
Net Cash Income		105,983
Return on Investment		31.9
Cost per liter of milk		37.6

Table 11 - Estimated annual costs and profits from three 150-cow dairies ir ne humid hill or mountain regi. with different levels of milk production and feeding systems 1/

	Model A		Model B		Model C	
	Cows producing 3,000 liters per lactation fed on grass alone 1/		Cows producing 4,000 liters per lactation fed on grass and concentrates 2/		Cows producing 5,500 liters per lactation fed on grass and concentrates 3/	
Item		Dollars		Dollars		Dollars
Laborers (4 at $7,000/year) 4/		28,000		28,000		28,000
Fertilizer (153 tons at $200)		30,000		30,000		30,600
Limestone (153 tons at $10)		1,530		1,530		1,530
Concentrate feed		--	(81 T/$220)	17,820	(212 T/$220)	46,640
Other feeds		2,900		2,900		2,900
Taxes (property, S.S., etc.)		5,200		5,200		5,200
Electricity, water		3,000		3,000		3,000
Miscellaneous expenses		2,800		3,200		4,000
Purchase of replacements	(30/$600)	18,000	(30/$800)	24,000	(30/$1,000)	30,000
Interest on operating capital	($20,000)	2,000	($35,000)	3,500	($35,000)	3,500
Depreciation of buildings (20 years)	($40,000)	2,000	($50,000)	2,500	($50,000)	2,500
Depreciation of equipment (10 years)	($20,000)	2,000	($24,000)	2,400	($24,000)	2,400
Depreciation of pastures (20 years)	($30,600)	1,530	($30,600)	1,530	($30,000)	1,530
Interest on capital investment (at 10%)		31,860		36,260		39,260
Total Costs		130,820		161,840		201,060
Income						
Sale of milk (at $0.48/liter)	(135/3,000)	194,400	(135/4,000)	259,200	(135/5,500)	356,400
Sale of culled cows for beef	(25/$400)	10,000	(15/$400)	6,000	(10/$400)	4,000
Sale of culled milk cow of fair quality and condition		--	(10/$600)	6,000	(15/$600)	9,000
Sale of calves for beef	(110/$35)	3,850	(55/$35)	1,925	(55/$35)	1,925
Sale of calves to be raised as milk cows		--	(55/$60)	3,300	(55/$70)	3,850
Total Income		208,250		277,425		375,175
Net Income		77,430		115,585		174,115
Cash Income		114,820		158,275		219,805
Return on capital investment		34.4%		41.8%		54.3%
Cost/liter of milk		32.3¢		30.0¢		29.8¢

Table 11 (Cont.)

Item		Model A Cows producing 3,000 liters per lactation fed on grass alone 1/ Dollars		Model B Cows producing 4,000 liters per lactation fed on grass and concentrates 2/ Dollars		Model C Cows producing 5,500 liters per lactation fed on grass and concentrates 3/ Dollars
Capital Investment						
Land (ha)	(66 at $2,000)	132,000	(66 at $2,000)	132,000	(66 at $2,000)	132,000
Cows	(150 at $600)	90,000	(150 at $800)	120,000	(150 at $1,000)	150,000
Bulls (3 at $2,000)		6,000		6,000		6,000
Buildings		40,000		50,000		50,000
Equipment		20,000		24,000		24,000
Pastures, fences, etc.		30,600		30,600		30,000
Total Capital Investment		$318,600		$ 362,600		$ 392,600

1/ Fed exclusively on grass pasture and receiving no concentrate feeds.
2/ Pastures + 0.4 kg of concentrates/liter of milk produced in excess of 10 daily but never less than 0.8 kg daily.
3/ Pastures + 0.5 kg of concentrate/liter of milk produced in excess of 10 daily but never less than 0.8 kg daily.
4/ Farmer shares in the work as needed for which he is compensated by the net income divided from the farm.

Table 12 - Estimated annual costs and profits for a 66/ha farm in the humid hill or mountain region dedicated to growing out young cattle for slaughter or raising heifers for dairy replacements on intensively managed grass pastures.

Item	Growing out young cattle for slaughter Dollars	Raising dairy heifers on a consignment basis Dollars
Costs		
One laborer at $4,000/year	$ 4,000	$ 4,000
Fertilizer (150 tons at $200)	30,000	30,000
Limestone (150 tons at $10)	1,500	1,500
Other material (salt, medicines, etc.)	1,000	1,000
Other expenses (light, water, etc.)	500	500
Replacements of 5 animals lost by death	1,000	1,000 1/
Taxes (property, Social Security, Health Insurance, etc.)	1,000	1,000
Interest (10%) on operating capital	1,300	500
Depreciation of pastures and fence in 20 years	1,500	1,500
Interest on capital investment at 10 percent ($225,000) 2/	22,500	16,500
Total Cost	$ 64,300	$ 57,500
Income 3/		
Net income (loss)	(4,300)	14,500
Cash Income	19,700	30,500

1/ Owner of heifers bears half of loss

2/ Capital investment:
66/ha of land in pastures = $165,000; cattle = 300 head x $200 = $60,000. There is no investment in heifers raised on a consignment basis.

3/ Beef cattle = 300 head gaining 200 kg per head yearly at $1.00/kg. Payment of $20/head monthly for dairy heifers.

Table 13 - Estimated annual costs and profits for a 66/ha farm in the humid hill or mountain region dedicated to two types of cow-calf operations on intensively managed grass pastures.

Item	Cow belly with one calve	Culled dairy cow with 2 calves
Costs		
One laborer at $4,000/year	$ 4,000	$ 4,000
Fertilizer (150 tons at $200)	30,000	30,000
Limestone (150 tons at $10)	1,500	1,500
Other materials (salt, medicines, etc.)	1,000	1,000
Replacements of lost by death	2,000	2,000
Loss in sale of replaced cows	1,500	1,500
Taxes (property, Social Security)	1,000	1,000
Other expenses	500	500
Purchase and transportation of calves	--	8,000
Depreciation of pasture and fences in 20 years	1,500	1,500
Interest (10%) on operating capital	1,000	1,800
Interest (10%) on capital investment 1/	21,800	21,800
Total Costs	$ 65,800	$ 74,600
Income-sale of calves, weighing 200 kg at $1/kg (130) 2/	26,000	(260) 52,000
Net loss	(39,800)	(22,600)
Net cash income	(17,500)	(700)

1/ Capital investment:	66/ha in pastures at $2,500	$ 165,000
	cattle (170 cows at $300)	51,000
	Three bulls	2,000
	Total	$ 218,000

2/ 80 percent of cows producing a weaned calf yearly.

Fig. 1.- Potassium uptake by Pangola grass from 50 different soils over a 4-year period of continuous cropping in pots.

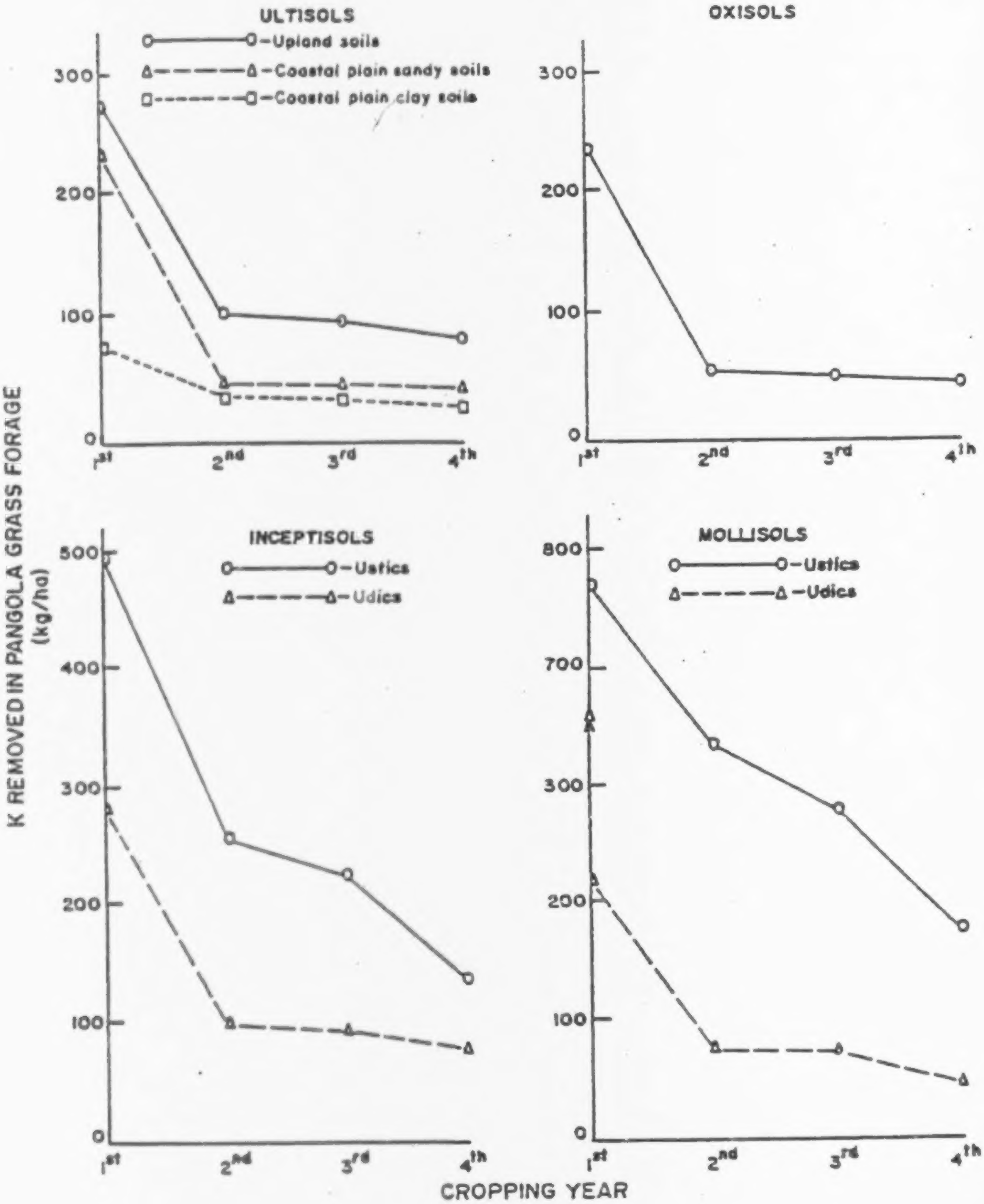


Fig. 2. Effect of nitrogen fertilization on yield of grasses harvested by cutting every 60 days.

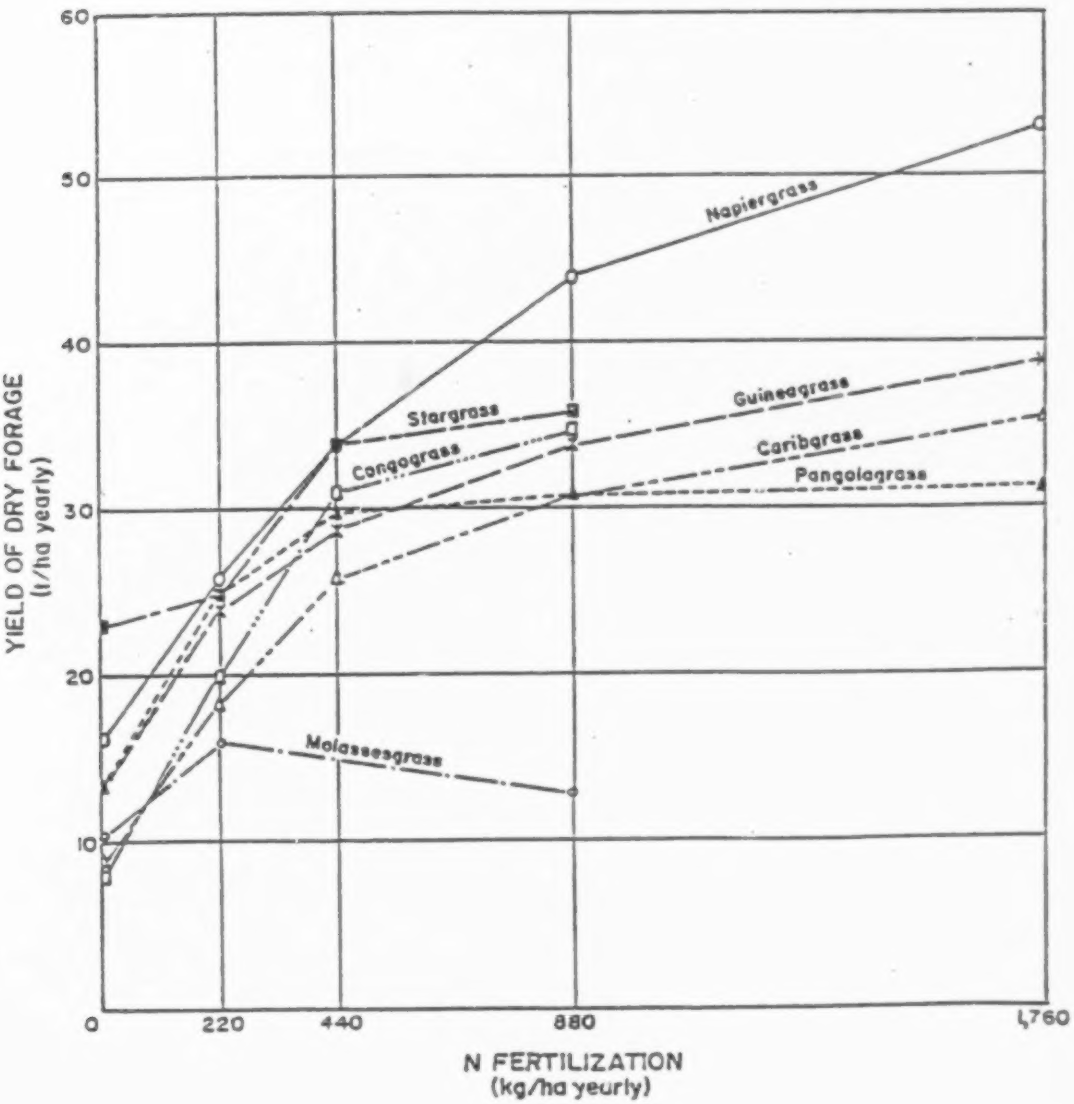


Fig. 3 .- Effect of frequency of cutting on productivity of well-fertilized grasses over a 2-year period. Numbers show intervals between cuttings in days.

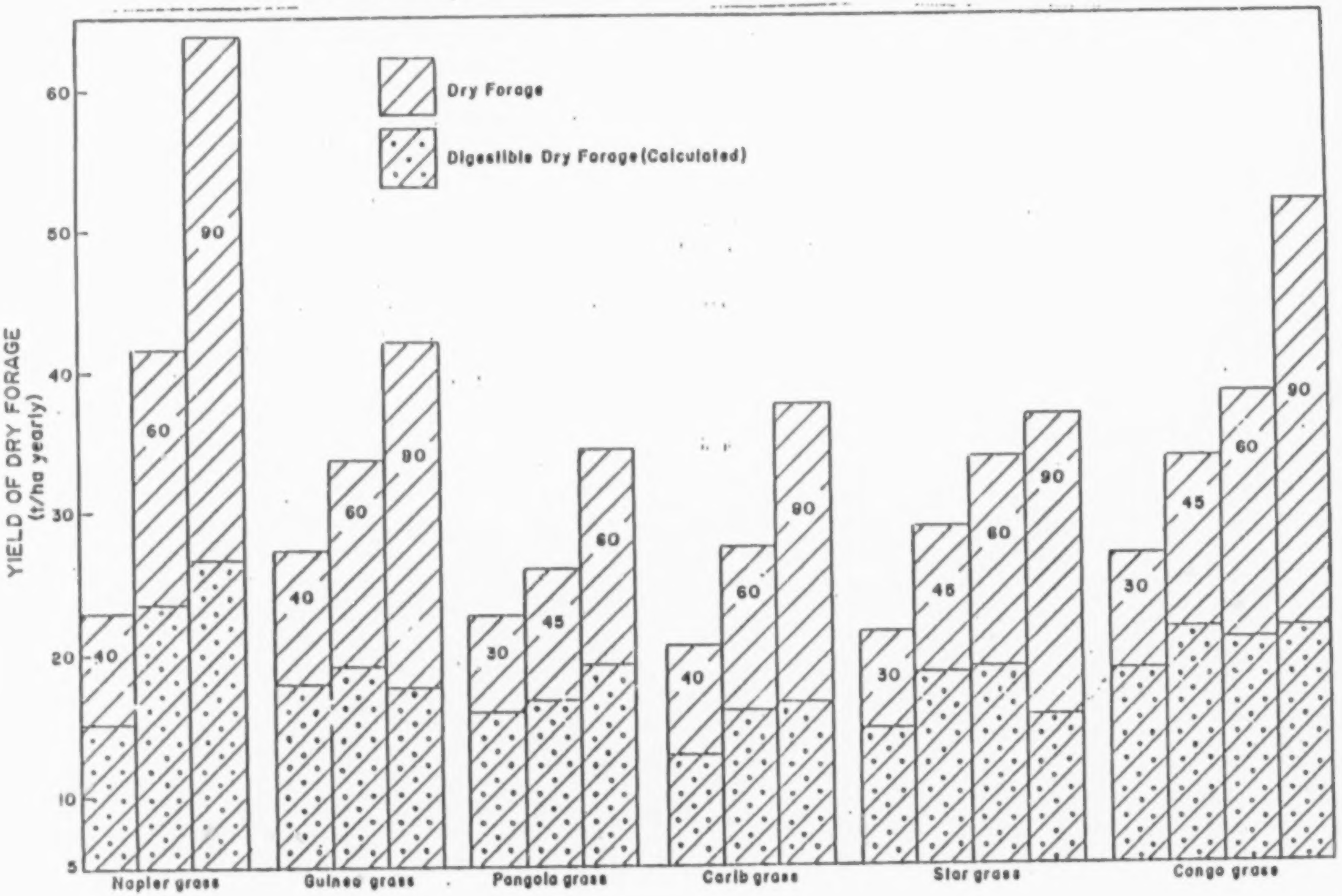


Fig. 4.- Effect of age on in vitro digestibility of five grasses compared to calculated digestibility according to McDonald (58).

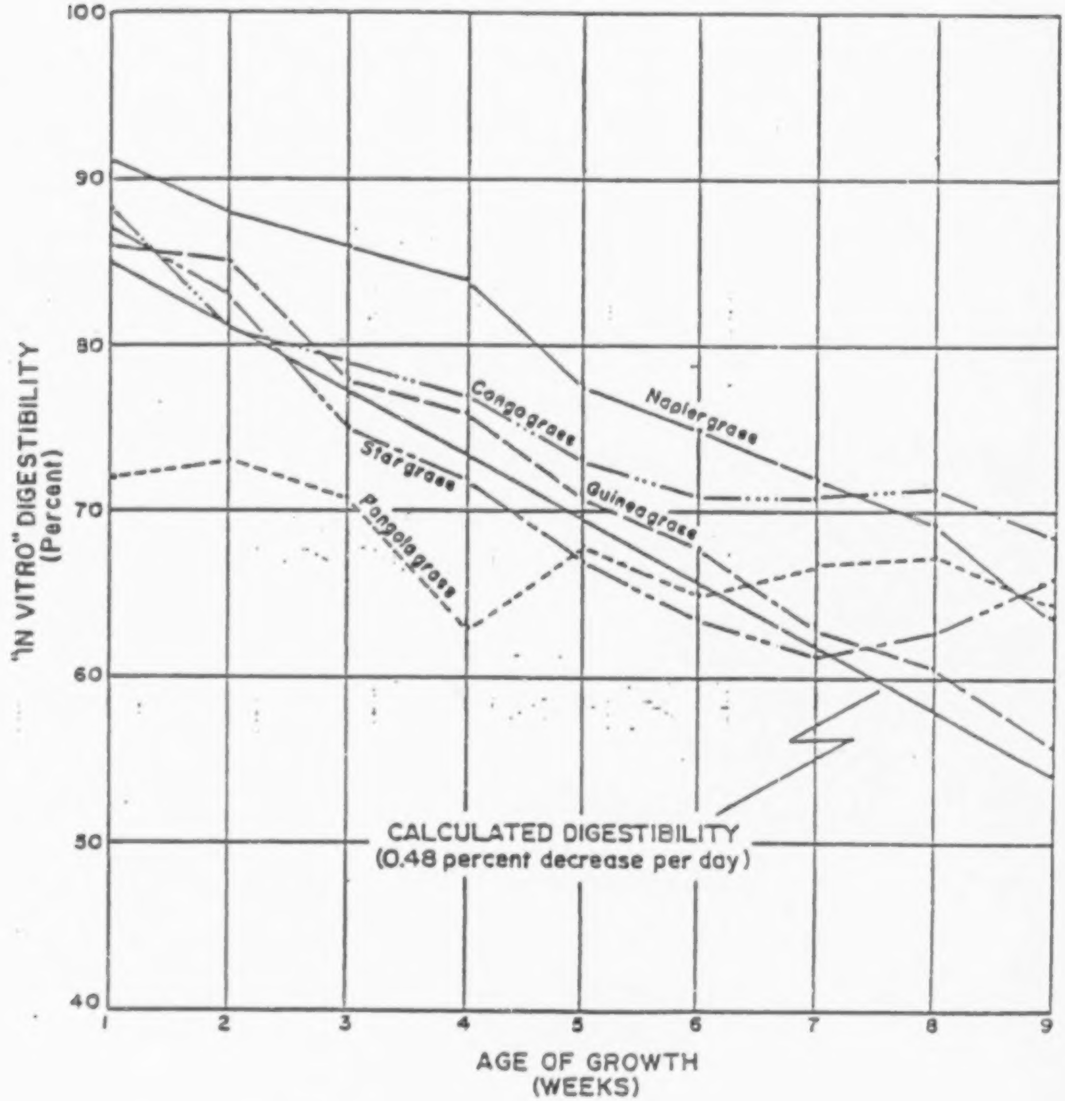


Fig. 5 .- Yield and protein content of forage harvested by cutting compared with that consumed by grazing cattle. In both cases grasses received two tons of 14-4-10/ha yearly.

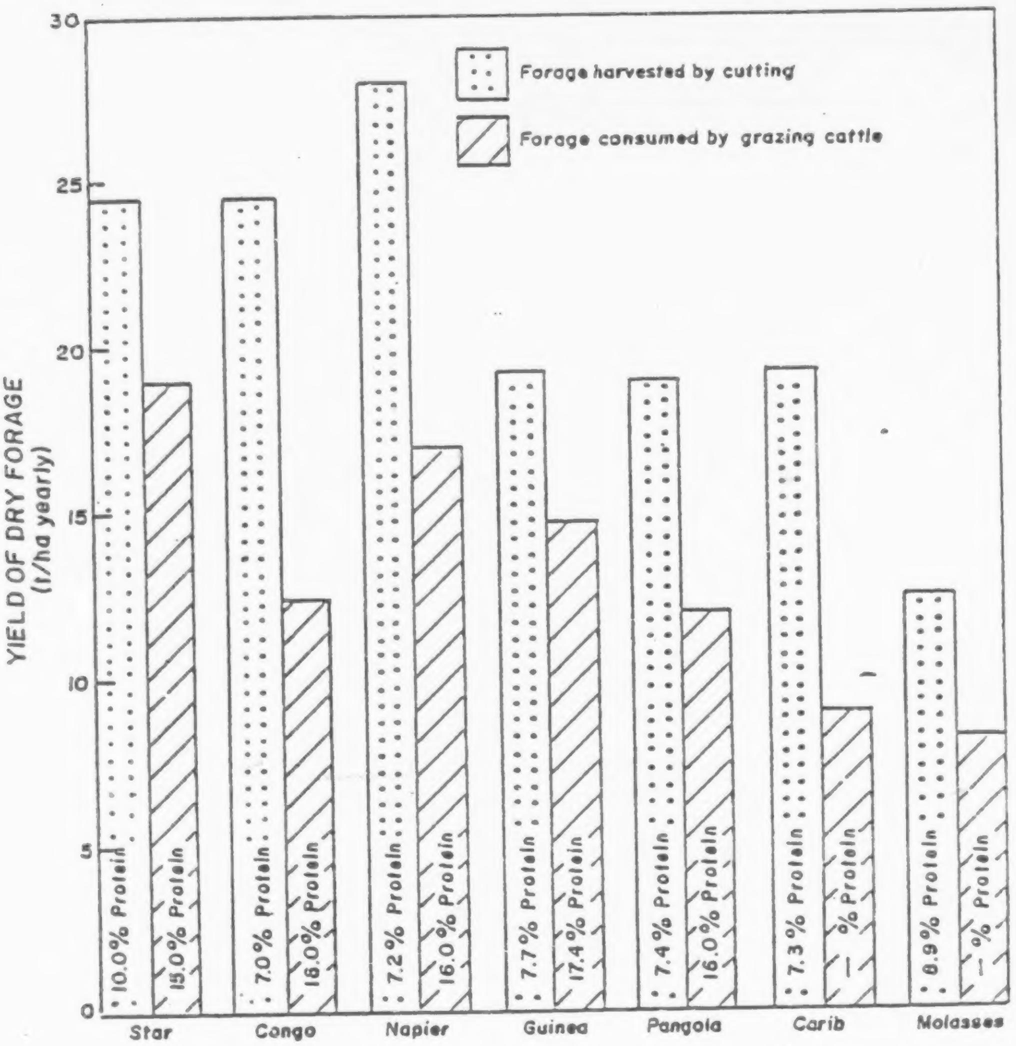
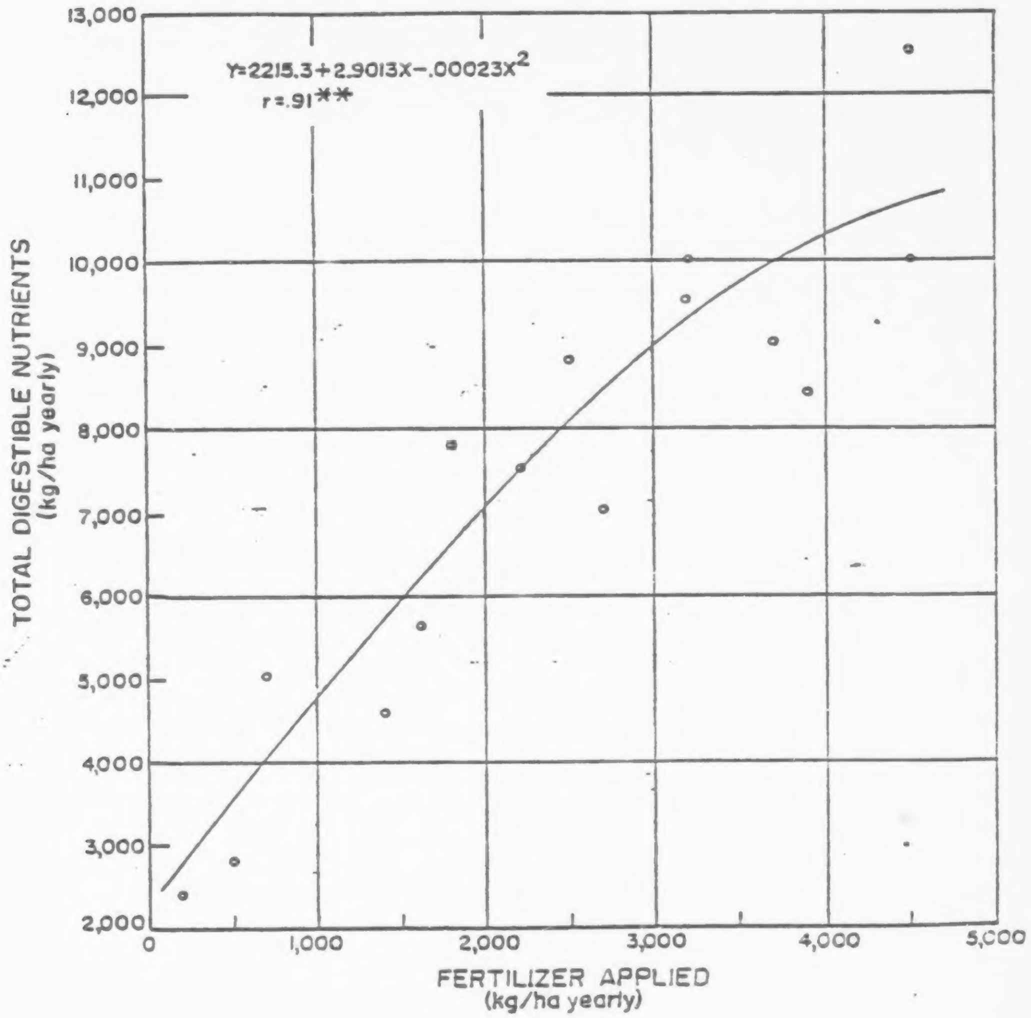


Fig. 6 .- Effect of fertilizer rates on total digestible nutrients ingested/ha/year by young cattle grazing three grasses over several years of experimentation



Background Paper No. 6

THE PUERTO RICAN FOOD PROCESSING INDUSTRY: ASSESSMENT OF PROCESSING TECHNOLOGIES

(Author's Draft)

by

Ferdinand Sanchez-Nieva

1986

Prepared for

U.S. Congress, Office of Technology Assessment,
Integrated Renewable Resource Management for U.S. Insular Areas,
Washington D.C.: U.S. Government Printing Office, 1987.

TABLE OF CONTENTS

THE PUERTO RICAN FOOD PROCESSING INDUSTRY

Abstract . . . .

Introduction . . . .

Pre-1950 period. . . . .

Three Decades of Development
The fifties, sixties and seventies . . . .

The food industry in the eighties. . . . .

Processing technologies. . . . .

Laws and regulations . . . .

Constraints and opportunities for growth . . . . . .

Appendix 1

Technologies developed for the Puerto Rican food processing industry, description and assessment . . . .

Literature cited . . . .

References on standard processing technologies . .

THE PUERTO RICAN FOOD PROCESSING INDUSTRY

F. Sánchez-Nieva

ABSTRACT

The Puerto Rican food processing industry had an early start canning grapefruit sections, and juice for the Mainland U. S. market. At a later stage prior to 1950, the main products manufactured for export were canned pineapple, dehydrated copra, brined and candied citrons, grapefruit juice and sections and pigeon peas. During this early stage, industry operated with a low level of technology, but processed mainly local crops for the local and export markets.

During three decades, the fifties, sixties and seventies, taking advantage of tax incentives and industrial development programs, industry had a rapid growth both in diversification and sales volume. Due to the failure of agriculture to provide the larger part of the raw material needed for processing, a shift to the processing of imported raw material was observed.

By March 1984, 320 establishments processing food and kindred products were in operation in Puerto Rico providing over 22,000 employment. Many of the plants are owned or are subsidiaries of US companies, while others are owned by local

companies. A wide range of products are manufactured using advanced technology. Due to restraints in the production of raw material locally, industry depends heavily on imported raw materials. The manufactured products are aimed to the Mainland and local markets. Many types of specialties aimed to the Hispanic markets in the U. S. are manufactured.

Local industry must comply with both Federal and Commonwealth laws and regulations which make mandatory the use of good manufacturing practices and standards to assure the safety and quality of the products manufactured.

THE PUERTO RICAN FOOD PROCESSING INDUSTRY

INTRODUCTION

The Puerto Rican food and kindred product industry is a highly diversified industrial operation, with 320 establishments manufacturing a large number of products, such as fruits and vegetables, meat, grain, milk and dairy products, bakery products, sugar and confectionery, alcoholic beverages, soft drinks, fats and oils, coffee and animal feeds. These establishments provide a total employment of 22,961 with an average hourly earning of $4.88. Sixty-four percent of the manufacturing plants were owned by local companies (31), 28% were subsidiaries of U. S. companies, and 8% were owned by foreign companies.

The consumer demand for food and kindred products in P. R. in 1982 (31) amounted to 3,364 million dollars. The value of imports amounted to 1,712 millions, of which 73% came from the United States and 27% from foreign countries. During this period the total value of export amounted to $1,115 millions, 81% of which went to the U. S. and 19% to foreign countries.

The food processing industry in Puerto Rico depends heavily on imported raw material. Local production for processing is limited to sugar, fluid milk, poultry, coffee, rice, pineapples, and to a lesser extent miscellaneous fruit and vegetables crops. Although industry could have the capability of processing locally produced agricultural commodities, the scarcity of the required raw material and its high price have forced the food processing industries to look for other sources.

Even though industry cannot depend on local raw materials for processing, it showed a rapid growth during the past three decades, with a marked increase in the number of processing establishments and volume of sales. It is a modern industry using modern equipment and up to date technologies.

DEVELOPMENT OF THE PUERTO RICAN FOOD PROCESSING INDUSTRY PRE-1950 PERIOD

The Puerto Rican food processing industries had an early start when grapefruit sections were first canned in the Island for shipment to the United States. Probably due to insect infestation which limited production and to the development of the grapefruit canning industry in the Southern states, the canning of grapefruit sections gradually phased out.

In the year 1947, (Piñero and Serra, 1952), 47 plants were engaged in the processing of agricultural products. The value of sales amounted to $5,498,518, of which 92% came from sales in the United States, and only 8% from sales in Puerto

Rico. The main products manufactured for export were canned pineapple, dehydrated copra, brined and candied citrons, canned grapefruit juice and sections, and pigeon peas. Products manufactured for the local market included fruit juices, jams, jellies, fruit bars, fruit flavored sirups and fruit wines. Sweet bars prepared from guavas, bitter oranges, mangos and sweet potatoes were the best sellers in the local market. With the exception of some minor ingredients, all raw material processed were produced locally.

Except for the products processed for the export market, most of the other fruits and vegetables had practically no value in the raw state. Some of the fruits and vegetables processed were grown by small farmers, others, like guavas and mangoes, grew wild.

Despite the fact that industry at that time operated with a low level of technology, with inadequate facilities for processing and storage of raw and processed products, it played an important part in providing economic benefits to both the agricultural and industrial sectors (Piñero and Serra, 1952). This was the only time that the Puerto Rican food processing industry processed only locally produced raw material.

THREE DECADES OF DEVELOPMENT

THE FIFTIES, SIXTIES AND SEVENTIES

Beginning in the late forties, the Government of Puerto Rico launched an aggressive program to industrialize the Island. The diversification of agriculture from the traditional sugarcane, coffee and tobacco crops became an important objective of the new program. The agricultural development strategy included the development of a strong livestock industry and crops with processing potentials.

To achieve the goals of the new program, tax incentives, technical assistance, labor training programs, low rental on government owned buildings and other related benefits were offered. Parallel with the industrial development program agricultural programs with incentives for growers and agribusiness were established. To provide the technology needed for the utilization of the crops to be developed, a Pilot Plant for rum manufacture and a Food Technology Laboratory were established at the Agricultural Experiment Station of the University of Puerto Rico.

To foster the rapid development of processing industries which could serve as a foothold for further developments, emphasis was given to the utilization of crops with a potential for processing and which could be grown successfully in the Island. The technologies needed for processing were available or were developed at the Food Technology Laboratory. A brief description of the projects developed during this period with their final outcome follows:

The canning of sweet potatoes had become a very important operation in Louisiana and other Southern states. In Puerto Rico, the yellow sweet potatoes varieties suitable for processing could be grown with high yields. Two processing plants were established for canning sweet potatoes. To provide raw material for processing, incentives were given for the production of sweet potatoes. These two plants remained in operation for a short while only and the commercial production and canning of sweet potatoes was a complete failure.

Guavas, mangoes and soursop were available from wild plantings. Therefore, priority was given to develop methods for canning nectars from these fruits. (See Appendix 1) As a result, several canneries were established to can nectars and other products. Efforts were also made to establish commercial plantings of guavas. Mainly due to the susceptibility of some of the varieties planted to a fungal disease, low yields, and to the high cost of harvesting the fruit, commercial plantings of guavas were a failure. With a dwindling supply of raw materials, some canneries closed and other shifted to the production of guava products from imported raw material.

Oranges were produced in fairly large quantities in coffee farms in the highlands. To utilize the orange crop a plant for manufacturing orange concentrate was built. After a few years in operation, due to the high cost of the raw material and the lack of adequate supply, the production of frozen juice concentrate from local oranges was discontinued.

Recipes and methods for the canning of about twelve different types of native style soups were developed by the Food Technology Laboratory of the P. R. Agricultural Experiment Station. Marketing tests indicated a very good acceptance for these products. A modern plant was established for processing these soups. After an unsuccessful attempt to compete with Campbell Soup Co., the production of soups was dropped and the plant was used for canning other products.

A modern plant was also built for the freezing of plantain, bananas and root crops. Methods for processing were developed at the Food Technology Laboratory, and programs to establish commercial plantings to supply the raw material for processing were patronized by the Commonwealth government. Eventually this plant closed. During this same periods, plantain chips were produced by some of the fried snack manufacturers, but finally dropped from their lines.

Mangoes, guavas, and bitter orange sweet bars, guava jellies, jam and marmalades were good sellers in the local market. Probably due to the scarcity and high cost of the raw material and high operating costs, most of these processing plants closed. Now most of the guava and some other fruit preserves found in the supermarket shelves are imported.

Copra and other coconut products were produced in Puerto Rico, some of which were exported. A canned coconut cream which later became very popular for the preparation of the drink PIÑA-COLADA was produced by a local manufacturer. With the exception of some types of coconut candies manufactured in small scale or in a family type operation, most of the coconut products are now manufactured elsewhere, some in processing plants owned by local manufacturers.

During this period,large commercial plantations to produce tomatoes for processing were established on the southern coast by Libby, McNeill and Libby, Inc. A processing plant was built to process tomatoes and other fruit and vegetable products. After a few years in operation, the production of tomatoes for processing was discontinued. The cannery continued in operation processing other products.

The very high ascorbic acid content of West Indian Cherries (Acerolas) aroused world wide interest. A state side company patronized the establishment of acerola plantations in Puerto Rico and built a plant to manufacture concentrates and dehydrated juice for the enrichment of baby foods and other food products. After a few years in operation, the production and processing of acerolas was discontinued because of economic reasons.

Even though some of the agribusiness projects failed, the food processing industry showed a rapid growth during the 1960-70 decade, both in diversification and sales volume. By 1972 (Rodríguez de Zapata, 1975), about 127 establishments were operating in Puerto Rico processing, coffee, fruits, vegetables and root crops. These plants purchased fruit and fruit products with a total value of $7,813,198 of which 65% was used to purchase imported raw material. The purchase of root crops and vegetables amounted to $5,289,812 of which 89% was used to purchase also imported products. During these three decades, a definite shift from processing locally produced fruits and vegetables to the processing of imported raw material took place.

During this period, the fruit and vegetable processing industry had available the technology needed for the manufacturing of high quality product, technical assistance in production, quality control and marketing, tax incentives, etc. However, the failure of local agriculture to provide raw material for processing at a reasonable cost forced industry to rely heavily on the processing of imported raw and semi processed fruit and vegetable products.

Fortunately, other sectors of the food processing industry fared better. The dairy,poultry and egg production increased greatly during this period and modern facilities for the production, handling and processing of these products were established. Other sectors of industry, like those manufacturing special goods with specific market targets also had a healthy growth.

THE FOOD INDUSTRY IN THE EIGHTIES

According to the Census of Manufacturing Industries of Puerto Rico (29) 320 establishments processing food and kindred products were in operation in Puerto Rico by March 1984. These plants were classified as follows:

Industrial Group	No. of Establishments
Preservation of fruit, vegetable and meat products	69
Milk and dairy products	25
Grain mill products	18
Bakery products	100
Sugar and confectionery	24
Raw, refined sugar and molasses	6
Confectionery products	18
Malt, beer, wines, distilled and other liquors	11
Bottled and canned soft drinks, carbonated waters, flavoring extracts and sirups	22
Fats and oils, miscellaneous preparations and kindred products	52

Many United States firms have subsidiaries operating in Puerto Rico. Of these, twenty eight are Fortune 1000: Beatricc Food Co., Borden, Unc., Castle Cooke, Inc., Central Soya, Inc., Coca Cola Co., Conagra, Inc., CPC international, General Foods Corp., H. H. Heinz, I. C. Industries Inc., NBI Nabisco Brands, Pepsico, Ralston Purina Co., Warner Lambert Co. (31)

A wide variety of products are manufactured. The most important groups of products are listed in the following tabulation:

Hamburguers and beef patties
Ham and sausages
Lard and vegetable oil
Poultry processing
Milk and milk products
Ice creams
Custards
Fruit drinks and nectars
Gelatins
Pastries and cakes
Cheese
Tomato sauce
Canned food products
Fruit bars
Fruit preserves
Seasonings
Mayonnaise
Chocolate
Frozen foods
Fritters and fritter mixes
Flour
Animal and pet food
Rice processing
Crackers and cookies
Candies and chewing gums
Bread
Beer
Wines
Rum
Soft drinks
Liquors and cordials
Tuna fish
Coffee
Snacks
Sugar and Sugar products

Following the trend of the previous decades, food manufacturing at present is highly diversified. The food processing industry is a healthy and strong manufacturing sector primarily processing raw material imported from the United States and foreign countries. Some of the products manufactured are directed to the local and hispanic markets in the United States. Both in the local and export markets, the Puerto Rican food processing industry must compete with products manufactured in the United States and from low wages foreign producing and manufacturing areas. The dairy, poultry and egg sectors must compete in the local market with products imported from the United States and which usually sell for a lower price.

PROCESSING TECHNOLOGIES

The technologies used by the Puerto Rican food processing industry come from different sources. The United States with its sophisticated and well developed food processing industry, and with a strong food science research program being conducted in universities, government laboratories and private companies, is a primary source of these technologies. No less important sources of manufacturing technologies are the equipment and supplies manufacturers and distributors who provide their customers with technologies and other information related to the products they sell. The University of Puerto Rico Agricultural Experiment Station provides industry with the technologies needed for the manufacture of rum, tropical fruit and vegetable products and some food specialties. (See Appendix 1)

The products manufactured using technologies in use in the United States and elsewhere are listed in the following tabulation:

- Cereal and cereal products
    - Corn and wheat flours
    - Rice milling
    - Bread, crackers, and cookies
    - Cakes, pastries, confectioneries
    - Pastas - macaroni and spaghetti
- Candies
    - Hard candies
    - Chewing gums
    - Chocolate and chocolate products
- Fats and oils
    - Lard refining and packing
    - Corn, soy and olive oil(Bottling)
- Flavoring agents
    - Packing of herbs and spices
    - Formulation of flavoring extracts
- Fish and fish products
    - Tuna canning
    - Cod fish processing
- Drinks
    - Soft and carbonated
- Fried snacks
    - Potato chips, corn,cheese,etc.
- Meat and meat products
    - Canned vienna sausages
    - Refrigerated miscelaneous sausages
    - Cured and smoked hams
    - Refrigerated breaded beef cuts
    - Refrigerated veal cuts
    - Hamburguer and meat patties
- Milk and milk products
    - Fluid milk
    - Skim milk
    - Chocolate flavored milk
    - Butter
    - Cheese
    - Ice creams
    - Puddings
    - Custard
- Poultry and eggs
    - Refrigerated broiler and friers whole and in parts.
    - Egg cleaning and packaging
    - Egg processing

From the above list, animal feeds, ice and other kindred products included under Industry Group 20 have been excluded. The manufacture of some of these products involves only a packaging operation requiring no special technologies.

A brief description of the processing of some livestock and agricultural commodities by the use of advanced or special

technologies follows: Rice: The commercial production of rice was initiated in Puerto Rico a few years ago. Storage and drying facilities and a modern rice milling operation for the milling, enrichment and packaging of rice, have been constructed on the North coast near the city of Arecibo.
Milk and milk products: The production of milk is the most important agribussiness in Puerto Rico. The milk is transported to the six pasteurizing plants in stainless steel refrigerated tank trucks. The milk is pasteurized in modern plants with stainless steel equipment and packed in 1 qt. cardboard containers and in 1/2 and 1 gal. plastic jugs. The processing plants make home deliveries of pasterized fluid milk and some other products like skim milk, chocolate milk and fruit flavored drinks.

Surplus milk is processed into butter, cream, skin milk and cheese in a central processing plant. Recently this plant started the production of UHT 2% fat partly skim milk. This product which keeps without refrigeration for several months is expected to compete with UHT milk from the United States and Canada which have been available in supermarkets for quite some time.

Other milk products manufactured are ice cream and ice cream mixes, custards puddings and yogurt. Although recipes may vary to suit the local palate, manufacturing technologies are standard for the industry.

Poultry and eggs: Two modern plants are in operation for the slaughtering, processing and packaging of chicken. Whole birds and parts are packed for the wholesale and retail trade and sold refrigerated. No frozen chicken is produced ar present.

Large quantities of eggs are produced locally. The eggs are cleaned, inspected and classified by size and packed in standard 1 doz. or 1 1/2 doz carboard or plastic containers. Under existing regulations, the packages should have stamped the date in which they were packed.

Eggs not qualifying for the fresh market are processed in a central facility.

Fruits -

Brine fermentation - The only fruit preserved in Puerto Rico by brine fermentation is citron. This is one of the oldest fruit processing operations in the Island. Years ago Puerto Rico was one of the largest suppliers of brined citron to the world markets. Methods for the brining and candying of citrons in Puerto Rico were described by McCullock (1927). To open new markets for this fruit, methods were developed for the canning of preserves and fruit bars (Cancel and Hernández, 1974, 1977).

Fruit, Juices, Nectars and Drinks - With the exception of pineapple juice which is produced directly from the fresh fruit, all other juices, nectars and drinks are prepared by dilution of frozen or hot packed pulp or concentrate. Juices, if not extracted directly from the fruit, can only be prepared single strength by dilution of a concentrate. Nectars are prepared by dilution of the pulps to desired consistency. Stabilizers or thickening agents, sugar or other sweetener, citric acid and artificial color may be added as needed to give a product of desirable flavor, mouth feel and color. Since these products are acid, a short flash pasterization is only needed for their preservation.

Passion fruit for processing is now produced in Puerto Rico. The fruit is processed in a plant operated by an association of local producers, la Federación de Desarrollo Agrícola, located near Guayama. The method for processing passion fruit was described by Seale and Sherman (1960). The bulk of the product is packed in institutional size containers for remanufacturing purposes.

Fruit pulps: Most of the pulps used in Puerto Rico for the manufacture of nectars, drinks, sirups and fruit bars are imported. Recently the same plant producing passion fruit is manufacturing guava, tamarind and soursop pulps packed aseptically in instituional size flexible containers for remanufacturing purposes.

Fruit bars or "pastas de frutas"

Fruit bars may be prepared from guavas, mangos, pineapp and coconut. A similar product is also prepared from white sweet potatoes. These products were very popular with the older generations. Guava paste served with white native style cheese was considered to be a typical Puerto Rican dessert. The bar or "pasta" is a firm pectin jam which holds its shape during handling and storage. Methods for its manufacture have been described (Rieckehoff and Rodríguez, 1960, and by Cancel and Hernández, 1977). Fruit bars which were at one time one of the main products manufactured for the local market in the early fifties, have been losing ground to the point that the guava bars available in many supermarkets are imported from Brazil. The local production of these products is very limited at present.

Vegetable products - Pigeon pea is the only vegetable grown in Puerto Rico which is at present canned. The canning of pigeon peas, which in the fifties and sixties, was one of the largest canning operations in the Island, has been going down hill lately, due to the high cost of raw material and to the competition from other Caribbean countries. Methods for canning and freezing pigeon peas have been described by Sánchez Nieva et al, (12-84). Although frozen pigeon peas are better in quality than the canned product (Sánchez Nieva et al. 1961), it has never been produced in commercial scale in Puerto Rico.

Tomato sauce - Tomato sauce is canned in a fairly large scale. The product is prepared from imported tomato paste which is diluted to proper consistency. Corn starch, stabilizers, salt, spices and herbs are added. The product is hot packed in 7 1/2 oz. cans.

Pulses or legumes - Another type of product canned in fairly large quantities are the pulses or legumes which include among others red kidney, pink, navy white and black beans and chick peas or "garbanzos". All pulses or beans are processed in a similar way. The dry beans are soaked in water overnight. The soaked beans are washed, to remove foreign material, blanched, and sorted to remove defective units. The product is usually canned in 2% brine in 303 cans and processed in retorts at 240° or 250°F for the time specified in the registered process. Some canners add tomato sauce as an optional ingredient. Besides beans packed in brine, some canners also produce Spanish style stewed beans. All the beans and chick peas canned in Puerto Rico are imported.

Root crops, plantain and banana products

The root crops processed are cassava, and taniers. Most of the products processed are imported from the Dominican

Republic. The products manufactured are frozen cassava and mashed taniers.

Bananas are grown as a cash crop and temporary shade for coffee in the highlands. The fruit is ripened under controlled conditions for the fresh fruit market (Sánchez Nieva et al. 1969). The green fruit can be also frozen (Sánchez Nieva and Mercado, 1978). This product was manufactured for a while in commercial scale, but when the processing plant closed, no further processing of green bananas has been atempted.

Green plantain products such as fried slices (tostones) and fried chips (platanutre) are very popular in Puerto Rico. Methods for the preparation of these products were described by Cancel et al. (1962) and by Sánchez Nieva et al. (1975). The fate of the commercial processing of these products has already been mentioned.

Specialties

The local food industry produces a group of products directed to the Hispanic markets in the Mainland and to the local market. Some of these products are manufactured by the larger processors, others are produced by smaller firms for the local market only. Formulas are considered a trade secret, as well as some manufacturing technics. A brief description of some of these products follows:

Sofrito is a special formulated sauce with Spanish flavor used as condiment. Basically it consists of a mixture of ground green peppers, onions, garlic, peppers, coriander or other flavoring herbs, ham, and tomato paste. The pH is controlled by the addition of acid or vinegar to a level safe for hot packing in glass jars without the need of retorting.

Recaito - Recaito is a mixture of onions, garlic, peppers, coriander and other herbs. It may be packed into glass jars by hot filling after adjusting the pH or in plastic containers for freezing.

Pastelillos and empanadillas

These are two types of turn-overs which are fried for serving and are a very popular mid-morning snack. These products are manufactured by several processors ranging from the small ones who prepare and pack the product entirely by hand to the larger ones which are partially mechanized. The product consists of a wheat flour dough which is spread fairly thin with rollers. Circles about 6 in. in diameter are cut. A filling is placed in the center of the dough circle and one half is folded over the other and crimped. Different types of fillings are used: meat, cheese, pizza, fish, crabs, guava jam, etc. The product is sold refrigerated or frozen.

Another type of product manufactured which is very popular is known as Adobo. This product is used among other things to flavor meat or fish for cooking. It is prepared from dehydrated products which may vary in type and quantity with the product manufactured. Among other ingredients it may contain; dehydrated garlic, spices, coriander, monosodium glutamate, annato or an artificial color, and anticaking compounds. The product is packed in glass jars or in single serving aluminum packets.

The list of special products manufactured or directed to the Hispanic palate is too large to be included or described in this report. Goya de Puerto Rico alone advertises over 400 products under their well established brand name "Goya".

LAWS AND REGULATIONS

Being part of the United States the requirements of the Food and Drug Act must be complied with. Local industry that manufactures products for the interstate trade must comply with all Food and Drug regulations such as The Good Manufacturing Practice Regulations 21 CFR Part 128 b for low acid foods packed in hermetically sealed containers, labelling requirements, nutritional labelling, and standards of identity, quality and fill of container.

The regulation covering the manufacture of low acid foods and acidfied products was put into effect in Puerto Rico in the middle 70th. To comply with this regulation,some canners had to modify their processing system to meet the requirements of commercial sterilty of the products manufactured. The Good Manufacturing Practice Regulation requires that all operators of retorts, processing systems, aseptic processing and packaging systems, acidification and packaging systems and container closure inspection,to be under the operating supervision of a person who has attended a school approved by the Commissioner for giving instruction in these practices.

To help industry comply with these regulations, in cooperation with National Canners Association and with the approval and assistance of Food and Drug, the Food Technology Laboratory of the Agricultural Experiment Station of the University of Puerto Rico has been offering to local industry operators the trainning required by the regulations. Since the conferences are given in the Spanish language, on many occasions students from Spanish speaking Latin American countries attended the school.

Other laws and regulations which apply to the local food industries are the following: Inspection of meats under the Act of 1967 for the Safety of Meat under the responsibility of the Secretary of Agriculture; inspection and certification of processed poultry products (U.S. Dept. of Agriculture) voluntary regulations for grading of fresh and processed products under Department of Agriculture inspection,inspection and safety of marine products under services provided by the Department of Commerce.

Besides Federal laws and regulations, there are also a number of Commonwealth laws and regulations which apply to the food industry. All aspects related with public health and the safety of foods falls under the responsibility of the Department of Health. Quality standards and marketing regulations are the responsibility of the Department of Agriculture.

A list of these laws and regulations follows:

Food, Drug and Cosmetic Act, Act. No. 72, April 1940.
Adulteration of milk Act No. 234, 1974.
Adulteration of coffee, Act 24, 1928.
Use of enriched flour in the manufacture of bread and other products, Act. No. 6, 1952.
Enrichement of rice, Act. No. 430, 1951.
Labelling of coffee and coffee products, Act. No. 60, 1965.
Labelling of meat, Act 129, 1965.

Besides these laws, the Secretary of Agriculture has approved a number of regulations for the marketing of some agricultural commodities.

CONSTRAINTS AND OPPORTUNITIES FOR GROWTH

It is very difficult for anyone to discuss the opportunities for growth and the constraints which may affect the development of the Puerto Rican Food Industry in the future. Many factors which may restrain the growth of industry come into play such as the fate of the 936 section of Internal Revenue Act,the Caribbean Basin initiative, the twin plan concept, agricultural and agribusiness programs to be developed, new tax incentive programs now under consideration, the availability of capital, market restraints, etc. Predicting the outcome on the actions to be taken by the Commonwealth and Federal Governments on the above points is as uncertain as predictions made by gazing at a crystal ball.

First we must consider physical constraints. Puerto Rico has a good network for electricity production and distribution. It is very unlikely that the establishment of additional processing plants may be hindered by the lack of electricity. The cost of electric power, however is very high.

The Island is facing a serious problem of safe water supplies and adequate sewage disposal. This restrain might be overcomed by careful selection of the site to locate new processing plants and providing the necessary water treatment and sewage disposal systems.

This report shows that at present we are dealing with two types of food industries: those processing locally produced crops and those processing imported raw materials. The data included in this report shows that industries processing local crops did not fare too well in the past. The failure of these industries can be attributed mainly to the failure of the agricultural sector to provide the raw material of the quality needed for processing at a reasonable cost. Agricultural programs with long range objectives have been lacking. During the last few years the two principal political parties have won the elections in alternate periods of four to eight years. Unfortunately the point of views and objectives of both parties in regard to agricultural programs are quite different, resulting in that agricultural programs are changed to suit the objective of the government in office. Goldman (32) in a recent article in one of the local newspapers summarizes the uncertainties facing agribusiness and we quote "The question remains whether such programs will in the near future, take up the slack created by the arrest of industrial promotion created by the fact that section 936 is in limbo and threatened with extinction. We must assume that the programs required are sophisticated ones. Such programs are costly and private investment money is not readily available because of the high risks created by such hazzards as weather and pests." The future of new agricultural programs producing crops with a processing potential is at present uncertain. The Secretary of Agriculture has indicated in press conferences that the rice project on the North coast and the vegetable project on the South coast are under careful evaluation to decide if they will continue or not.

A new development with processing potential is the plantir of 500 acres to mangos on the southern coast. A yield of 10,000,000 fruits per year is expected, primarily for the export fresh fruit market. Irradiation of the fresh fruit to control insect pests and processing of surpluses are possible new developments.

The sector of industry processing imported raw material and manufacturing special products for specific marketing targets may have a good potential for development. Bacardi, one of the largest rum producers in the world, recently announced (Blasor and Fridman, 1985) that the company is venturing into the food bussiness launching a food product line directed to the stateside hispanic market. This company hopes to become a manufacturer, canning many of the foods it currently subcontracts companies here and in the Dominican Republic that sells on the mainland under the Batey label.

One growth constraint which industry in general must face is competition from lower wage areas. Besides, some industries like poultry and eggs, dairy and meat, must compete with products imported from the mainland which generally sell at a much lower price.

It is my opinion that the application of modern technologies in the processing of food products in Puerto Rico does not restrain its growth potential. Industries have available a large number of processing methods and quality control procedures (Sánchez Nieva, 1980) for the processing of tropical crops. The availability of technologies from the United States, through association of the University of Puerto Rico with the other Universities of the Land Grant System, through services offered by stateside consultants and food equipment and ingredient manufacturers, assures the use of proper manufacturing technologies when needed. Many of the local processing plants are subsidiaries of Mainland companies and these of course have at their disposal all the technologies available at the parent company.

The application of technologies is many times hindered by the lack of properly trained personnel. In Puerto Rico this is not the case. The University of Puerto Rico and several private universities graduate each year thousands of students in engineering, science, business administration and other fields. At the Utuado Regional College, the University of Puerto Rico is offering courses leading to an associate degree in Food Technology. A fairly large number of Puerto-ricans also go to the Mainland Universities for graduate studies leading to masters and Ph.D. degrees.

Both the University of Puerto Rico and Commonwealth Economic Development Administration offer technical assistance to those industries with problems in the application of new technologies or quality control procedures.

APPENDIX 1

TECHNOLOGIES DEVELOPED FOR THE PUERTO RICAN FOOD PROCESSING INDUSTRY

PRODUCT	REFERENCES	ASSESSMENT
	CANNING	
West Indian cherries	Sánchez Nieva, F. (1955)	Method suitable to preserve the juice for enrichment, not for consumer's use.
Banana nectar	Hernández, I., (1973),(1976)	Method used in commercial scale for the preparation of enriched nectars.
Chironja sections, rind in syrup, juice	Benero et al. (1965) Cruz Cay, J. R. (1972) Pérez López et al. (1982)	Chironja products have never been processed commercially. Methods tested in pilot plant scale. Juices cannot be canned successfully.
Guava nectar	Sánchez Nieva, F. (1952) Sánchez Nieva, F. et al.(1965)	Processing methods were used commercially for canning guava nectars.
Guava pulp	Sánchez Nieva, F. et al.(1958)	Method used commercially for canning guava pulp for remanufacturing purposes.
Mango nectar and pulp	Sánchez Nieva, F. et al.(1959) Benero J., et al. (1971)	The combination of undiluted pulp extraction procedures and nectar manufacture techniques suitable for the production of high quality nectars.
Citron slices in sirup	Cancel, L. E., Hernández I. (1974)	Method used to prepare and can citron products for the institutional trade.

APPENDIX 1 (Cont.)

TECHNOLOGIES DEVELOPED FOR THE PUERTO RICAN FOOD PROCESSING INDUSTRY

PRODUCT	REFERENCES	ASSESSMENT
Papaya drinks, nectars and slices in syrup	Rodríguez, A.J., et al. (1971) Rodríguez, A.J., et al. (1972) Cancel L.E. et al. (1969)	Procedures developed in pilot plant scale and used commercially for canning papaya products.
Green pigeon peas	Sánchez Nieva, F.,et al.(1961) Sánchez Nieva, F.,et al.(1964)	Methods tested in pilot plant scale for canning and to assure the quality of the product were adapted to commercial production according to the availability of processing equipment.
Dry pigeon peas	Sánchez Nieva, F., Hernández I. (1964)	Method tested in pilot plant scale and in commercial production for canning dry pigeon peas.
Pineapple syrup for canning	Cancel L. E. et al. (1964)	Method for preparing a canning syrup from canning wastes. Not used commercially.
Plantains, ripe	Rivera J. M., Hernández I. (1976)	Method developed for canning ripe plantains in sirup; due to short shelf life of product its commercial use is questionable.
Soursop nectar	Sánchez Nieva, F. et al. (1953)	Basically the method used by industry to prepare and can soursop nectar.

APPENDIX 1 (Cont.)

TECHNOLOGIES DEVELOPED FOR THE PUERTO RICAN FOOD PROCESSING INDUSTRY

PRODUCT	REFERENCES	ASSESSMENT
Sweet potatoes	Sánchez Nieva,F. et al.(1958) González et al. (1961)	Processing methods adapted to the characteristics of local cultivars. Sweet potatoes were canned for a short while only
Tamarind drinks	Benero J., et al.(1974)	Procedures developed in pilot plant scale for the canning of tamarind, soursop and tamarind-soursop drinks, and modified for use in commercial scale.
	FREEZING	
Banana puree (Ripe)	Hernández, I. (1973)	A frozen puree was developed for the preparation of canned banana nectar. Method was used commercially in the canning of banana nectar.
Freezing of green bananas	Sánchez Nieva, F. and Mercado, M. (1978); Sánchez Nieva, F. et al. (1980)	Method tested in pilot plant scale. Frozen green bananas were produced in commercial scale.
Citrons, fermented in brine.	Cancel, L. E., Hernández, E. R. (1979)	Freezing of citrons for candying could result in considerable saving in the use of salt, space needed for storage and shipping costs.

APPENDIX 1 (Cont.)

TECHNOLOGIES DEVELOPED FOR THE PUERTO RICAN FOOD PROCESSING INDUSTRY

PRODUCT	REFERENCES	ASSESSMENT
FREEZING		
Coconut pulp and milk	Cancel, L.E. et al.(1976)	Pilot plant method for freezing coconut pulp and extraction of the milk. Coconuts are no longer processed in commercial scale.
Native dishes	Lefebre de González, L.A., (1968)	Excellent frozen dishes were developed. Some were produced commercially but could not compete with frozen diners from the U.S.
Guava nectar base	Sánchez Nieva, F.et al.(1970)	Pilot plant process. Frozen guava products not produced in commercial scale.
Green pigeon peas	Sánchez Nieva, F.et al.(1961)	Product market tested with a very high acceptance. Never produced commercially in P. R.
Pineapple slices	Sánchez Nieva, F., Hernández I. (1977)	Quality of frozen slices from two local varieties low, not suitable for commercial production.
Plantains, ripe	Sánchez Nieva, F., Hernández I., (1967)	Pilot plant method for producing high quality ripe plantain in sirup. Product produced commercially for consumers for a short while.

APPENDIX 1 (Cont.)

TECHNOLOGIES DEVELOPED FOR THE PUERTO RICAN FOOD PROCESSING INDUSTRY

PRODUCT	REFERENCES	ASSESSMENT
	FREEZING	
Soursop puree	Sánchez Nieva, et al.(1970)	Pilot plant method, never used commercially.
Taniers	Sánchez Nieva, et al.(1977) Sánchez Nieva, F., Parsi,O. (1977) Sánchez Nieva, F., Caloni I. B. (1979)	Basic procedures for freezing taniers. Frozen Mashed taniers available to consumers.
	DEHYDRATION	
Green banana flour	Rodríguez Sosa, E.J., et al. (1977)	A method was tested for producing green banana flour in a cabinet drier. Green banana flour not produced commercially at present.
Brined citrons	Benero, J. R. et al.(1970)	Method devised for reducing shipping cost of brined citrons. Not in use.
Plantain flour	Rahman, A. (1963)	Economical method developed for the production of green plantain flour. The flour has been produced sporadically in P. R. by other methods.
Plantain flakes	Rahman, A. (1964)	Plantain flakes suitable to substitute breakfast cereals can be produced, but product is too expensive for commercial production.

APPENDIX 1 (Cont.)

TECHNOLOGIES DEVELOPED FOR THE PUERTO RICAN FOOD PROCESSING INDUSTRY

PRODUCT	REFERENCES	ASSESSMENT
DEHYDRATION		
Sweet peppers	González, M.A. et al. (1970)	Sweet peppers are dried by freeze drying. Product is of good quality but too expensive for commercial use.
Tanier flakes	Rodríguez Sosa, E.J. (1977)	Dehydrated instant flakes can be used in the preparation of meat pies and forcemeat, commercial possibilities doubtful.
FRIED PRODUCTS		
Plantain chips	Cancel, L.E. et al. (1962) González, M.A.,et al.(1969)	Process used in commercial production. Plantain chips no longer produced in large scale.
PRESERVES		
Citron bars	Cancel L. E. and Hernández E. R. (1977)	Method for producing fruit bars from citrons. Use of the method in commercial practice unknown.
Guava juice	Sánchez Nieva, F.,et al. (1957)	Method for bottling guava extract for jelly manufacture. Method was used successfully in commercial scale.

APPENDIX 1 (Cont.)

TECHNOLOGIES DEVELOPED FOR THE PUERTO RICAN FOOD PROCESSING INDUSTRY

PRODUCT	REFERENCES	ASSESSMENT
	PRESERVES	
Guava jelly	Rieckehoff, I.G., Rodríguez, A. J. (1960)	Method for the production of high quality jellies, used successfully in commercial scale.
Guava Bar	________________, (1960)	Method for the preparation of guava bars used successfully in commercial scale.
	Rodríguez, A. J. (1962)	A consummer acceptance test of bars packed in aluminum containers and in rectangular cardboard boxes. The rectangular boxes were preserved. However guava bars are now packed in cans in Brazil.
	SUGAR SYRUPS	
Guava flavored syrup	Colon Fortis, B. (1967)	Method developed for the preparation and bottling of three types of syrup. Guava syrups are produced in commercial scale but it is not known whether the methods developed are used.

APPENDIX 1 (Cont.)

TECHNOLOGIES DEVELOPED FOR THE PUERTO RICAN FOOD PROCESSING INDUSTRY

PRODUCT	REFERENCES	ASSESSMENT
SUGAR SYRUPS		
Liquid sugar	Smith, B.A. et al. (1963)	Method developed jointly by the Agricultural Research Service, Southern Research Center and the Puerto Rico Agricultural Exp. Sta. Food Technol. Lab. for the production of confectionery grade liquid sugar from raw sugar by ion exchange. Process in use commercially to produce liquid sugar.
PROCESSING TECHNOLOGIES		
Fermentation of citrons	Cancel, L.E. (1975	Method for recycling fermented brine to lower production costs. Commercial use of method unknown.
Coconuts	Cancel, L.E. et al. (1971) (1974)	A machine was designed and patented for breaking the coconuts. A method using a continuous press for the extraction of the milk was tested in pilot plant scale. Although the method proved suitable for processing coconuts, this nut is not processed in large scale in P. R. anymore.

APPENDIX 1 (Cont.)

TECHNOLOGIES DEVELOPED FOR THE PUERTO RICAN FOOD PROCESSING INDUSTRY

PRODUCT	REFERENCES	ASSESSMENT
	PROCESSING TECHNOLOGIES	
Coffee cleaning and washing	Cancel L. E. et al. (1972) (1974); Hernández, E. R. (1983)	A system for cleaning and washing coffee harvested with plastic nets was developed. The use of this method in commercial scale made possible the harvesting of coffee with plastic nets.
Papaya peeling	Cancel, L.E. Rodríguez Sosa,E. (1970)	A method for lye peeling of green papayas for processing was developed.
Soursop pulp	Benero, J. R., Rodríguez, A. J. (1971)	A continuous method was developed for the extraction of undiluted pulp. Using this procedure both the pulp and nectar can be produced commercially.
Tamarind pulp	Benero, J. R. et al. (1972)	A method was developed for the mechanical extraction of tamarind pulp overcoming the drawbacks of the cumbersome hand peeling and extraction procedures.
Lye peeling of taniers	Sánchez Nieva, F., Hernández, I. (1977)	Lye peeling of taniers makes possible the processing of this tuber in commercial scale substituting the more expensive hand peeling method.

APPENDIX 1 (Cont.)

TECHNOLOGIES DEVELOPED FOR THE PUERTO RICAN FOOD PROCESSING INDUSTRY

PRODUCT	REFERENCES	ASSESSMENT
PROCESSING TECHNOLOGIES		
Control of browning in lye peeled taniers	Sánchez Nieva, F. (1977)	Control of browning by sulfitation makes possible the use of lye peeling and the production of high quality roots for freezing.
Ley peeling of yams	Rivera-Ortiz, J.M. González, M.A. (1972)	A method of lye peeling to substitute the more expensive and cumbersome hand peeling.
HARVESTING AND STORAGE		
Ripening bananas, Montecristo Cultivar	Sánchez Nieva, F.,et al.(1969)	One of the problems encountered in processing tropical crops is the lack of knowledge on methods for prolonguing the shelf life of the fresh produce. Another serious problem in processing these crops is the lack of indices or other means to harvest when the crop is at the optimum stage of maturity or development for processing. The methods listed in this section were developed to solve these problems with the crops indicated.
Chironjas, storage	Díaz N. (1976)	
Mangos, storage	Cancel, H.L., García Pérez T. (1979)	
Papayas ripening	Rodríguez A. J. et al.(1974)	
Green pigeon peas, Harvesting	Sánchez Nieva,F.et al.(1960) (1963) Benero J.R. et al. (1980) (1981)	

APPENDIX 1

TECHNOLOGIES DEVELOPED FOR THE PUERTO RICAN FOOD PROCESSING INDUSTRY

PRODUCT	REFERENCES	ASSESSMENT
HARVESTING AND STORAGE		
Green plantains ripening and storage	Sánchez Nieva, F.et al. (1970), Hernández, I. (1973)	
Pineapple storage	Cancel, H.L. (1974)	
Yams (Dioscorea spp)	González, M.A. et al. (1972) Rodríguez, E.J. et al.(1981)	
EVALUATION OF VARIETIES FOR PROCESSING		
Pigeon peas	Sánchez Nieva, F.(1962)	One of the main problems encountered in food processing is related to the processing characteristics of the crops. Variations in quality may result from genetic characteristic as well as from the influence of ecological factors. Therefore, every variety of unknown characteristics should be evaluated from the processing point of view,manufacturing the products for which they are intended. This was the purpose of the research here outlined.
Rice	Benero,J.R., González,M.A. R. de Hernández , E. et al. (1982), 1983)	
Mangos Dry beans	Rodríguez Sosa, E.J. et al. (1984)	

LITERATURE CITED

1. Benero, J. R., and Carlo-Vélez, L. A. (1965), The canning of chironja sections, J. Agri. Univ. P. R., 49(3):388.

2. Benero J. R., Cancel, L. E., Rivera, A. L. (1970), Dehydration of fermented citrons, J. Agri. Univ. P. R. 54(3):508-516.

3. Benero, J. R. and Rodríguez, A. J., (1971) Mango pulp extracting method, J. Agri. Univ. P. R. 55(4):513-515.

4. Benero, J. R. and Rodríguez, A. J. (1971), Soursop extraction procedure, J. Agri. Univ. P. R. 55(4):518-519.

5. Benero, J. R., Rodríguez, A. J. and Collazo de Rivera, A. (1972), A mechanical method for the extraction of tamarind pulp. J. Agri. Univ. P. R. 56(2):185-186.

6. Benero, J. R., Collazo de Rivera, A. and Iguina de George, L. M. (1974), Studies on the preparation and shelf life of soursop, tamarind and soursop-tamarind soft drinks, J. Agric. Univ. P. R. 58(1):99-104.

7. Benero, J. R. and González, M. A. (1978), Cooking characteristics, eating quality and preference of some rice varieties, grown experimentally in P. R., J. Agric. Univ. P. R. 62(2):171-177.

8. Benero J. R., Acevedo, E., Ortiz, H. and Rodríguez, A. J. (1980) Maturity pattern of 2B-Bushy green pigeon peas, J. Agric. Univ. P. R. 64(4):400-406.

9. Benero, J. R., Ortiz, H., Acevedo, E., and Rodríguez, A.J. (1981), A method for determining optimum harvesting date of 2-B Bushy pigeon peas, J. Agri. Univ. P. R. 65(1):43-49.

10. Blasor, L. and Fridman, H. L. (1985), Bacardi Muscles into U.S. food market, The San Juan Star, Sunday, Sept. 8.

11. Cancel, L. E., González, M. A. and Sánchez Nieva, F., (1962) Manufacture of plantain chips, Pub. 6, Food Technol. Lab., Agri. Exp. Sta. Univ. P. R.

12. Cancel, L. E., González, M. A., and Sánchez Nieva, F. (1964), Utilization of pineapple canning wastes- Preparation of a syrup for canning pineapple slices, Bull 135, Agri. Exp. Sta. Univ. P. R.

13. Cancel, L. E. and Rodríguez Sosa, E. (1969), A method for the preparation of papaya slices in syrup, Pub. 10, Food Technol. Lab., Agri. Exp. Sta. Univ. P. R.

14. Cancel, L. E. and Rodríguez-Sosa, E. (1970), Lye peeling of green papaya, J. Agri. Univ. P. R. 54(1):19-27.

15. Cancel, L. E., Rivera, J. M. and Santos-Sánchez, M. (1971), Effect of the amount of water on the extraction of coconut milk, J. Agri. Univ. P. R. 55(2):167-173.

16. Cancel, L. E., Rivera Ortiz, J. M. and Ruiz de Montalvo, C. (1972), Separation and washing of coffee harvested with plastic nets, J. Agri. Univ. P. R. 56(1):11-17.

17. Cancel, L. E., Rosario Hernández, J. A. (1974), Extraction of coconut milk by continuous screw press, J. Agri. Univ. P. R. 58(3):322-328.

18. Cancel, H. L. (1974), Harvesting and storage conditions for pineapples of the Red Spanish variety, J. Agri. Univ. P. R. 58(2):162-169.

19. Cancel, L. E., Hernández Torres, I. and Hernández, E. R. (1974), Method for canning citrons in sirup, Pub. 84, Agric. Exp. Sta. Univ. P. R.

20. Cancel, L. E., Hernández Torres, I. (1974), Improvement in the washing operations of coffee harvested with plastic nets, J. Agric. Univ. P. R. 58(1):1-10.

21. Cancel, L. E. (1975), Recycling of fermented brine in citron curing, J. Agri. Univ. P. R. 59(3):199-267.

22. Cancel, L. E., Rivera, J. M., and Hernández, E. R. (1976), Storage of frozen coconut pulp and quality of coconut milk extracted, J. Agri. Univ. P. R. 60(1):99-104.

23. Cancel, L. E. and Hernández, E. R. (1977), Effect of pH on texture and organoleptic evaluation of citron bars packed in plastic films. J. Agric. Univ. of P. R. 61(3)290-299.

24. Cancel, L. E. and Hernández, E. R. (1977), Chemical changes in citrus fruit bars due to pH changes during processing, J. Agri. Univ. P. R. 279-289.

25. Cancel, L. E. and Hernández, E. R. (1979), Effect of blanching and freezing on the quality of frozen citron fruit pulp, J. Agri. Univ. P. R. 63(3):309-314.

26. Cancel, H. L. and García Pérez, T. (1979), Effect of fruit size on the ripening of Edward Mangoes, J. Agric. Univ. P. R. 63(4) 460-464.

27. Colón Fortis, B. (1967), The preparation of three types of guava syrup, Pub. 8, Food Technol. Lab. Agric. Exp. Sta. Univ. P. R.

28. Cruz-Cay, J. R. (1972) Processing chironjas, J. Agr. Univ. P. R. 56(2):183-184.

29. Department of Labor and Human Resources, Commonwealth of P. R., Census of Manufacturing Industries, 1984.

30. Díaz, N. (1976) Effect of storage at 45°F on the keeping quality of five chironja clones, J. Agri. Univ. P. R. 60(3):348-368.

31. Economic Development Adm. Commonwealth of P. R., The Food and Kindred Product Industry, December 1982.

32. Goldman, Max (1985), Alternatives to Section 936 fail to take up slack, The San Juan Star, Sunday Sept. 1.

33. González, M. A., Benero, J. R., Sánchez Nieva, F. (1961). Canning characteristics of the Cobre variety of sweet potato, J. Agri. Univ. P. R. 45(20:106-111)

34. González, M. A., Díaz Negrón, E., Sandoval, A. R. (1969) Studies on the stability of fried plantain chips, J. Agri. Univ. P. R. 53(1):67-74.

35. González, M. A., Díaz Negrón, E., Cancel, H., Rivera, A. C. (1970) Freeze drying of sweet peppers, J. Agri. Univ. P. R. 54(1):133-148.

36. González, M. A. and Collazo de Rivera, A. (1972), Storage of fresh yams, Dioscorea Alata under controlled conditions, J. Agri. Univ. P. R. 56(1):46-56.

37. Hernández I. (1973) Storage of green plantains, J. Agric. Univ. P. R. 57(2):100-106.

38. Hernández, I. (1973) Preparation and acceptability of banana nectar, J. Agri. Univ. P. R. 60(2):96-99.

39. Hernández, I. (1976) Vitamin enrichment of banana nectar, J. Agric. Univ. P. R. 60(2):250-251.

40. Hernández E. R., Guadalupe-Luna, R. B., de Caloni, I. (1982) Acceptability and keeping quality of marmalade and canned slices in syrup of some mango cultivars, J. Agri. Univ. P. R. 66(3):159-167.

41. Hernández, E. R., Benero, J. R. (1982) Evaluation of four mango cultivars for nectars, J. Agri. Univ. P. R. 66(3):153-158.

42. Hernández, E. R., Benero, J. R., Guadalupe-Luna, R. and Caloni, I. B. (1983) Evaluation of the Ruby mango cultivar for the manufacture of nectars and slices canned in heavy syrup, J. Agri. Univ. P. R. 67(2):165-166.

43. Hernández, E. R. (1983). Improved method for cleaning coffee harvested with plastic nets, J. Agri. Univ. P. R. 67(3):197-203.

44. Iefebre de González, L. A. (1968) Preliminary studies on the preparation and freezing of some native dishes, Pub. 9, Food Technol. Lab., Agri. Exp. Sta., Univ. P. R.

45. McCulloch, L. (1927) Brining and canding of citrons, U. S. Dept. of Agri. Circular 13, Washington, D. C.

46. Pérez López, A., Cruz Cay, J. R. and Benero, J. (1982) Behaviour of ten chironja clones at three site IV. Evaluation of fresh and processed fruit, J. Agric. Univ. P. R. 66(1):65-70.

47. Piñero M. and Serra, G. (1952) Economic study on the processing and canning of some agricultural products, Bull. 101, Agri. Exp. Sta. Univ. P. R.

48. Rahman, A. (1963) Economical methods for the production of flour from green plantains, J. Agri. Univ. P. R. (1):1-10.

49. Rahman, A. R. (1964), The development of plantain flakes, J. Agri. Univ. P. R. 48(3):26.

50. Rieckehoff, I. G. and Rodríguez, A. J. (1960) Preparation of guava jelly, Pub. 4, Food Technol Lab., Agric. Exp. Sta. Univ. P. R.

51. Rieckehoff, I. G. and Rodríguez, A. J. (1960) Preparation of guava bars, Pub. 3, Food Technol Lab. Agri. Exp. Sta. Univ. P. R.

52. Rivera Ortíz, J. M. and González, M. A. (1972) Lye peeling of fresh yams, Dioscorea alata, J. Agri. Univ. P. R. 56(1):51-63.

53. Rivera, J. M. and Hernández, I. (1976) Canning of ripe plantains in syrup, J. Agri. Univ. P. R. 60(2):248-249.

54. Rodríguez, A. J. (1962) Results of a consumer acceptance test of two types of containers for guava paste (bar) J. Agri. Univ. P. R. 45(2):140-143.

55. Rodríguez, A. J. and Iguina de George, L. M. (1971) Preparation and canning of a papaya drink, J. Agri. Univ. P. R. 55(2):161-166.

56. Rodríguez, A. J., and Iguina de George, L. M. (1972) Evaluation of papaya nectar prepared from peeled and unpeeled papaya puree, J. Agric. Univ. P. R. 56(1):79-80.

57. Rodríguez, A. J., Guadalupe, R., and Iguina de George, L. M. (1974) The ripening of local papaya cultivars under controlled conditions, J. Agri. Univ. P. R. 58(2):184-196.

58. Rodríguez-Sosa, E. J. and González, M. A. (1972) The preparation of yam flakes, J. Agri. Univ. P. R. 56(1):39-45.

59. Rodríguez Sosa, E. J. González, M. A., Caloni, I. B. and Parsi-Ros, O., The preparation of green banana flour, J. Agric. Univ. P. R. 61(4):470-478).

60. Rodríguez Sosa, E. J. (1977) Preparation of instant tanier, J. Agri. Univ. P. R. 61(1):26-31.

61. Rodríguez, E. J., Parsi Ros, O. and González, M. A. (1981) J. Agri. Univ. P. R. 65(1):50-57.

62. Rodríguez-Sosa, E. J., Caloni, I. B., Cruz Cay, J. R. and Badillo, F. (1984) Hydration and cooking properties of dry beans, J. Agri. Univ. P. R. 68(3):259-268.

63. Rodríguez de Zapata, L. (1975) Study of the industrial use of some agricultural products, Bull 239, Agri. Exp. Sta. Univ. P. R.

64. Sánchez Nieva, F. (1952) New procedures for the preparation of mango, guava and soursop nectars, Pub. 6, Agri. Exp. Sta. Univ. P. R.

65. ________________, Igaravidez, L. and López Ramos, B. (1953) The preparation of soursop nectar, Techn. Paper 11, Agri. Exp. Sta. Univ. P. R.

66. ________________, (1955) Extraction, processing, canning and keeping quality of acerola juice, J. Agri. Univ. P. R. 39(4):175-183.

67. ________________, Rodríguez, A. J. and Benero, J. (1957) Preparation and packaging of a guava juice for jelly making, Pub. 2, Food Technol Lab. Agri. Exp. Sta. Univ. P. R.

68. ________________, and Rodríguez, A. J. (1958), Extraction and canning of guava pulp, Pub. 1, Food Technol Lab. Agri. Exp. Sta. Univ. P. R.

69. ________________, Benero, J. and González, M. A. (1958) A comparison of the canning quality of Rico and UPR 3 seet potatoes, J. Agric. Univ. P. R. 42(4):224-232.

70. ________________, Rodríguez, A. J. and Benero, J. R. (1959), Processing and canning of mango nectars, Bull. 148, Agri. Exp. Sta. Univ. P. R.

71. Sánchez Nieva, F. (1952) Cancel, L. E. and Benero, J. R. (1960) Maturity indices for pigeon peas, J. Agr. Univ. P. R. 44(2)60-69.

72. ________________, González, M. A. and Benero, J. R. (1961) The freezing of pigeon peas for market, J. Agri. Univ. P. R. 45(4):205-216.

73. ________________, Rodríguez, A. J. and Benero, J. R. (1961) Improved methods for canning pigeon peas, Bull. 157, Agri. Exp. Sta. Univ. P. R.

74. ________________, (1961) The influence of degree of maturity on the quality of canned pigeon peas, J. Agri. Univ. P. R. 45(4):217-231.

75. ________________, González, M. A. and Benero, J. R.(1961), The effect of some processing variables on the canning of pigeon peas, J. Agri Univ. P. R. 45(4):223-258.

76. ________________, (1962), Processing characteristics of pigeon peas of the Kaki and Saragateado selections, J. Agric. Univ. P. R. 46(1):23-33.

77. ________________, Benero, J. R. and González, M. A. (1963), Variations in the maturity of pigeon peas during the harvesting period, Bull. 170, Agri. Exp. Sta. Univ. P. R.

78. ________________, Benero, J. R. and González, M. A. (1964), Effect of maturity on the quality of canned pigeon peas, Bull. 177, Agri. Exp. Sta. Univ. P. R.

79. ________________, Benero, J. R. and González, M. A. (1964), Effect of harvesting method on the efficiency of the canning process, Bull. 179, Agri. Exp. Sta. Univ. P. R.

80. ________________, and Hernández, I. (1964), Recommendations for canning dry pigeon peas, Bull 186, Agri. Exp. Sta. Univ. P. R.

81. ________________, Rodríguez, A. J. and González, M. A. (1965), Removal of stone cells from guava nectar, J. Agri Univ. P. R. 49(2):234-243.

82. Sánchez Nieva, F. (1961), Hernández, I. (1967), Preparation and preservation of ripe plantains in syrup, Pub. 7, Food Technol. Lab. Agri. Exp. Sta., Univ. P. R.

83. ________________, Hernández, I. and Bueso de Viñas, C. (1969(, Ripening of Montecristo bananas, J. Agric. Univ. P. R. 53(3):274-283.

84. ________________, Hernández, I. and Bueso de Viñas, C. (1970) Effect of heat treatments on the quality and shelf life of frozen guava nectar base, J. Agri. Univ. P. R. 54(2):211-219.

85. ________________, Hernández, I. and Bueso de Viñas, C. (1970), Studies on the ripening of plantains under controlled conditions, J. Agri. Univ. P. R. 54(3):517-529.

86. ________________, Hernández, Iguina de George, L. M. (1970) Frozen soursop puree, J. Agr. Univ. P. R. 54(2):220-236.

87. ________________, Hernández, I., and Bueso C. (1975) Studies on the freezing of green plantains I. J. Agric. Univ. P. R. 59(2):85-91.

88. ________________, __________________, ______________,(1975) II., J. Agri. Univ. P. R. 59(2):92-106.

89. ________________, __________________, ______________,(1975) III., J. Agri. Univ. P. R. 59(2):107-114.

90. ________________, __________________, ______________,(1975) IV. J. Agri. Univ. P. R. 59(4):239-244.

91. Sánchez Nieva, F. and Hernández, I. (1977) Studies on the freezing of Puerto Rican Red Spanish and Smooth Cayenne pineapples, J. Agri. Univ. P. R. 61(3):345-360.

92. ______________, and Parsi-Ros, O. (1977), Preparation and freezing of mashed taniers, J. Agri. Univ. P. R. 61(4):507-508.

93. Sáchez Nieva, F., (1977) Control of browning in lye peeled taniers, J. Agri. Univ. P. R. 61(4):487-500.

94. ________________, and Hernández, I. (1977) Lye peeling of taniers, J. Agri. Univ. P. R. 61(3):354-353.

95. ________________, (1977) A comparison of the processing characteristics of three tanier cultivars, J. Agri. Univ. P. R. 61(3):337-344.

96. ________________, and Mercado, M. (1978) Effect of peeling method and sulfitation of the shelf life of frozen green bananas, J. Agri. Univ. P. R. 62(2):241-248.

97. ________________, __________________, (1978) Control of enzymatic browning of green bananas for freezing, J. Agri. Univ. P. R. 62(3):232-240.

98. ________________, __________________, (1978) Effect of peeling method on the absortion of aqueous bisulfite by green bananas, J. Agri. Univ. P. R. 62(2):191-197.

99. ________________, and Caloni, I. B. (1979) Frozen diced taniers, J. Agri. Univ. P. R. 63(2):268.

100. ________________, Mercado M., and Bueso, C. (1980) Effect of the stage of development at harvest on the texture, flavor, quality and yields of frozen green bananas, J. Agri. Univ. P. R. 64(3):275-282.

101. ________________, (1980) An annotaed bibliography of processing research conducted at the Food Technology Laboratory, 1951-1979, Pub. 139, Agri. Exp. Sta. Univ. P. R.

102. Seale, P. E. and Donald Sherman-G. (1960) Commercial passion fruit processing in Hawaii, Circular 58, Hawaii Agri. Exp. Sta. Univ. Hawaii.

103. Smith, B. A., Sánchez Nieva, F., Vázquez, R. and Carlo, L. A. (1963) Raw sugar treated with ion exchange to produce two confectionery grades of liquid sugar, Sugar and Azúcar 58(4):33-36.

SELECTED REFERENCES ON STANDARD PROCESSING TECHNOLOGIES

Canning

1. Borgstrom, G. (1968) Principles of Food Science, The McMillan Co., N. Y.

2. National Canners Association, Laboratory Manual for Food Canners and Processors, Avi Publishing Co., Westport Conn. (1968)

3. National Canners Association, Canned Foods, Principles of Thermal Process Control and Container Closure Evaluation, The Food Processing Institute, Berkeley, Cal.

4. Stumbo, C. R. (1965), Thermobacteriology in Food Processing, Academic Press, N. Y.

Cereals

5. Chemistry and Technology of Cereals as Food and Feed, S. A. Matz, ed. The Avi Publishing Co., Inc. (1957)

6. Matz, S. A. (1969) Cereal Science, The Avi Publishing Co., Westport, Conn.

7. Rice, Chemistry and Technology, D. F. Houston, ed., Am. Assoc. of Cereal Chemist, St. Paul, Minn. (1972).

Fish and Fish Products

8. Fish as Food, G. Borgstron, ed., vol. 1-4, Academic Press, N. Y. (1965).

Freezing

9. Tressler, D. K., Van Ardel, W. B. and Copley, M. J. (1968) The Freezing Preservation of Foods, vol. 1-4, The Avi Publishing Co., Westport, Conn.

Eggs

10. Egg Science and Technology, W. J. Stadelman and O. J. Cotterill, editors, Avi Publishing Co., Westport, Conn (1973)

Juices

11. Tressler, D. K. and Joslyn, M. A. (1961), Frui and Vegetable Juice Processing Technology, The Avi Publishing Co., Westport, Conn.

Meat and Meat Products

12. American Meat Institute Foundation, The Science of Meat Products, W. H. Freeman and Co., San Francisco (1960)

Milk and Milk Products

13. Fundamentals of Dairy Chemistry, B. H. Webb and A. H. Johnson, editors, The Avi Publishing Co., Westport, Conn, 1965.

14. Lampert, L. M. (1965) Modern Dairy Products, Chemical Publishing Co. N. Y.

Poultry

15. Mountney, G. J. (1966) Poultry Products Technology, The Avi Publishing Co., Westport, Conn.

Wines

16. Amerine, M. A., Borg, H. W. and Cruess, W. V. (1967) The Technology of Wine Making, Avi Publishing Co., Westport, Conn.

Background Paper No. 7

ASSESSMENT OF ENERGY-INTEGRATED FARMING TECHNOLOGIES FOR U.S. INSULAR AREAS

by

Alex G. Alexander
Energy Cane, Inc.

1986

Prepared for

U.S. Congress, Office of Technology Assessment,
Integrated Renewable Resource Management for U.S. Insular Areas,
Washington D.C.: U.S. Government Printing Office, 1987.

TABLE OF CONTENTS

Topic   Page

INTRODUCTION
    1. Principles Of EIF Systems
    2. EIF Conditions And Projects For U.S. Insular Areas
SCOPE OF EIF SYSTEMS
    1. Small-Scale EIF Systems
    2. Large-Scale EIF Systems
        (a) Management Structure
        (b) Incorporation Of Energy Crops
        (c) Materials Transportation
        (d) Availability Of Information, Management, Labor
POTENTIAL OF EIF SYSTEMS
    1. Small-Scale
    2. Large-Scale
RESEARCH AND EXTENSION
SUMMARY: OPPORTUNITIES AND CONSTRAINTS
    1. Major Opportunities And Benefits
    2. Role Of U.S. Policies, Programs, Regulations
    3. Appropriate Objectives For Congressional Action
        (a) Environment Legislation
        (b) Economic Support (R & D)
        (c) Economic Support (Implementation)
        (d) Incentives And Subsidies
        (e) Administrative Organization
        (f) Caribbean Basin
    4. Other Institution Roles On Behalf Of EIF
        (a) U.S. Federal Government Agencies
        (b) Insular Governments
        (c) Private Industries
        (d) Academic Institutions
        (e) Non-Profit And International Organizations
    5. Forecast Of EIF Effects And Consequences
REFERENCES
FOOTNOTES
FIGURE LEGENDS
FIGURES

ASSESSMENT OF ENERGY-INTEGRATED FARMING TECHNOLOGIES FOR U.S. INSULAR AREAS

ABSTRACT

The nature, potential benefits, and implementation options of energy integrated farming (EIF) systems in the U.S. insular areas is broadly assessed. Prior experience with EIF projects on the mainland and in Puerto Rico is drawn upon in defining opportunities and constraints for EIF technologies development under widely-dispersed insular conditions. Emphasis is also given to the multiplicity of subsystems potentially available for management of manures, wastes, and plant residues at the small-farm and rural household level. In general, large reductions in regional fossil energy imports are not likely to occur via EIF technologies alone, but rather as integrated components of domestic renewable energy forms that include other sources of biomass, solar, wind, and OTEC.

Very serious constraints against EIF implementation are seen in the insular areas' enormous geographic dispersal, and in the operation of "environment-protection" concepts that have evolved in U.S. mainland consciousness and will ultimately emerge in "compliance" legislation for insular areas under U.S. control. The Pacific Basin on one hand, and the Caribbean Basin on the other, have had distinct prehistoric, historic, colonial, and modern features of human development that affect the realistic options for future EIF development. They also have favorable common assets such as tropical or subtropical climates, year-round growing seasons, and extensive biomass resources to be developed around the farm manures, digester sludge, and wastewater products normally associated with "biogas" fuels production in EIF systems. For both administrative and technical reasons it is recommended that any Federal EIF inputs to the Pacific-and Caribbean-Basin areas be directed through separate offices, ~~with~~ technical focus on existing EIF background and expertise within the University of Hawaii and the University of Puerto Rico.

Emphasis is also directed to the role of U.S. policies, programs, regulations, and appropriate objectives for Congress in adiding the implementation of EIF technologies for insular areas. Sources of funding for R & D and "demonstration" EIF systems, commercial financing, government subsidies and incentives, and interim accommodation with enviromental interests, are discussed in broad outline. Specific for Puerto Rico and the U.S. Virgin Islands, EIF opportunities are identified in the "Caribbean Basin Initiative" (CBI) policies being formulated by the current Federal Government. These include such features as unrestricted importation to U.S. markets, establishment of "twin plant" manufacturing agreements, and special tax incentives for manufacturers that could utilize EIF biomass by-products ("Section 936" of the U.S. Internal Revenue Code).

Favorable long-term impacts of EIF technology are forecast, but implementation probably would be longer and more frustrating than seemingly necessary. This view is based on limitations of funding, human resources (engineering, extension, administration), the constraints of geography and environment legislation, and experience of the DOE-sponsored EIF program on the U.S. mainland.

ASSESSMENT OF ENERGY-INTEGRATED FARMING TECHNOLOGIES FOR U.S. INSULAR AREAS

INTRODUCTION

"Energy-integrated farming" is a multi-dimensional concept having potential benefits for the world's agrarian populations irrespective of climate or level of social/technological development (5, 41, 89, 90, 60). Complete "packages" of energy-integrated farm (EIF) technologies have been demonstrated in a relatively few, well-supported instances confined to developed countries in temperate-climates. Their acceptance and practice on a massive scale has not occurred (5, 39, 49, 7, 10). Alternatively, certain elements and benefits of energy-integrated farm systems are widely accepted, whether under "EIF" designation or not, and have been used historically almost since the beginning of organized agriculture (10, 7).

1. Principles Of EIF Systems

The purpose of energy-integrated farming is to provide benefits to agricultural populations and enterprises through the utilization of organic wastes produced by their farm operations. Such benefits can be direct economic ones via reduction of expenditures for fuel and electricity, and indirectly economic through avoided costs of wastes disposal, EPA compliance equipment and its operation, the sales of new farm products, and increased yield and quality of traditional farm commodities.

Striking examples are seen in the use of cattle manures to produce a combustible gas ("biogas"), which is then burned for illumination, heating, or generation of electricity for the farm or farm-household needs (40, 18, 89, 90). In more sophisticated systems there is also recovery of water, proteins, and nutrients from the wastes (4, 3, 17). Their reutilization, or recycle, on the same farm is a less direct means of external energy substitution. Similarly, some of the raw manure can be used to fertilize the growth of cattle feeds or human food commodities, thereby substituting the purchase of chemical fertilizers whose manufacturing processes are highly consumptive of energy (11, 4, 8, 9). Moreover, the organic substrates for recycle need not be manures or even "wastes". Crop residues, leaves, succulent grasses, straw — virtually any organic material suitably prepared — can be used independently or in conjunction with manures to produce the combustible biogas fuel (41, 84, 56, 86).

The "biogas" product featured in most EIF designs is actually a mixture of gases in which the highly-explosive natural gas methane predominates (18, 5, 45, 57, 79). Biogas is produced in a closed, air-free container by several sets of "anaerobic" bacteria (45, 52). The same processes occur in nature, but they can be made vastly more efficient in "fermentors" or "digestors" where feedstock supplies, agitation, temperature, and other variables are controlled by man (18, 41, 45, 17, 79).

The principal byproduct of anaerobic fermentation is a viscous sludge (6, 84, 57, 17). It consists of water, organic solids (soil, grit), certain nutrient elements, and a range of organic compounds of variable value. It is relatively odorless and in some circumstances is disposed directly to the environment without further treatment. There are potential benefits of sludge processing for feed recovery and in the fertilization and irrigation of farm crops (4, 3, 5). Livestock digestive systems do not efficiently recover the crude protein, nutrients, and carbohydrate of their feed rations. Fermenter sludge having significant contents of undigested food components can be dried and blended with fresh rations, thereby susbstituting a fraction of new feed costs (up to about 25%). This is particularly true of confined poultry and cattle heavily reliant on costly imported "feed" (corn., barley, soybean, cottonseed meal, beet pulp, alfalfa). Alternatively, as in home gardening or intensive vegetables production, the sludge can be used directly as a soil conditioner and fertilizer supplement. Under similar circumstances the fermenter's effluent water could be a significant supplement to rainfall or other irrigation water resources.

To an important degree, the benefits of EIF systems are pegged to the stage of social/economic development enjoyed by the respective farm population. Employing the clean, bright flame of biogas for illumination and cooking would be a step upward for many people in Arica, Asia, and elsewhere (40, 89, 90, 41). As recently as the mid-1940's it would have been welcomed by rural communities in Puerto Rico. However, with the advent of rural electrification, even the poorest of agrarian families in Puerto Rico's interior uplands have access to utility power and the attendant benefits of electric lighting, television, kitchen appliances, etc. The older benefits of biogas would not be appreciated in the Puerto Rican farm household of the 1980's.

2. EIF Conditions And Projects For U.S. Insular Areas

Principles of energy-integrated farming in U.S. insular areas are strongly affected by circumstances that do not apply everywhere in the world or even on the U.S. mainland (22, 21, 23, 31, 36). First, the U.S. Virgin Islands, Guam, American Samoa and the U.S. Trust Territory of the Pacific Islands have tropical or subtropical climates, small land masses suited for farming, and "developing" social/economic profiles. Puerto Rico is the largest and most technologically advanced of the group, yet it remains an atypical case both by reference to the U.S. mainland's farming concepts and to its counterpart small nations throughout the developing tropical world (33, 5, 14, 6, 11).

A second circumstance is a distinctive impact in U.S. insular areas of the principles of "environmental protection" and its attendant obligations for an enforced compliance (5, 4, 22, 60, 37). This is a relatively recent concept to which U.S. public and governmental perception had gradually evolved. It nonetheless retains a substantive legal basis and enforcement mechanisms. To these the insular areas are directly obligated, or as in the case of Puerto Rico, have served as models for even more stringent compliance legislation by local insular lawmakers (5, 37, 14).

It is widely recognized that the manures and certain other wastes used as feedstocks in EIF systems are potential health hazards and sources of environmental polution (5, 41, 84). They offer sites and conditions for microbial pathogen development, insect breeding, emission of foul odors, and chemical contamination of surface and ground water resources (41, 37, 17, 30, 43). For such reasons, emphasis on farm waste management in the U.S. and Puerto Rico stems in part from the need to comply with environment-protection laws, not merely the need for on-farm sources of energy. For example, Puerto Rico's farmers must comply with the "State Solid and Hazardous Waste Management Regulatory Program", enforced by the Commonwealth

Environmental Quality Board (EQB), the insular counterpart of the Federal EPA, and monitored as well by the P.R. Department of Natural Resources[1].

Fortunately for the hard-pressed farmer, Puerto Rico's waste management laws are not strictly enforced, for to do so would close down a large segment of the insular dairy, swine, and poultry industries. For example, dairy and poultry farmers are allowed used of open-air holding ponds for aerobic breakdown of wastes and effluents as an alternative measure (5,41,83). It is recognized that the need for eventual full compliance with environmental concerns must be reckoned with in the planning of EIF systems in all U.S. insular areas. Human health is a particularly valid concern in heavily-populated islands such as Puerto Rico. While in Puerto Rico today the compliance with environmental regulations is probably more important than energy to EIF owners, the opposite would generally be true of mainland farmers where EPA regulations appear less heavy-handed and there is greater use of electricity.

Although their potential need has been recognized in a general way, very little has been done to implement energy-integrated farm systems in the U.S. insular areas (5, 22, 23, 31, 36). The principal exception is a complex of energy-integrated, environmental-compliance systems designed and partially installed at a dairy farm near Juana Díaz on Puerto Rico's semi-arid south coast (5, 4, 3). This project was sponsored by the U.S. Department of Energy, Energy Integrated Farm Systems Program, Idaho Operations Office[2]. Originally proposed in 1980 as a poultry and egg farm operation in Puerto Rico's humid uplands (41), it was relocated at the Ubarri-Blanes dairy farm owing to constraints of working space, manure supply, and unacceptable hillside excavation risks at the poultry farm's Río Grande watershed site (5, 3).

Although the CEER-UPR project was but one of some eight EIF projects funded simultaneously by DOE, it incorporated elements distinct from others of the group and have special meaning for the current interest in energy-integrated farming in U.S. insular areas. These include:

- Location in a continuously warm, tropical climate
- Location in a "developing nation" economic environment
- Location on an insular, area-constrained land mass
- Location on a hilly, arid, variable-soil site
- Design emphasis on environment as well as energy
- Design emphasis on multiple feed products
- Design emphasis on wastewater treatment
- Design emphasis on gravity flow of materials
- Inclusion of aquaculture subsystems
- Inclusion of a wind-powered subsystem
- Inclusion of solar-drying subsystems
- Inclusion of a tropical "greenfeed" subsystem

While comprehensive, the Phase I systems plan approved by DOE has had only partial success in its implementation. Much of its greenfeed, irrigation, and manure-recycle components were installed in 1982-83 while the project leader for the Juana Díaz site selection and Phase I systems analysis and design was still with the CEER-UPR biomass energy program (11, 6, 9). The systems for manure preparation and biogas production were constructed in 1983-84, and electrical power generation began in the spring of 1985. Approximately 40 percent of the farm's electricity needs are currently being supplied by this means (59). Conversely, the farm's sludge treatment components for feed recovery and wastewater cleanup remain incomplete.

In terms of time-delays and general technical difficulties, the Puerto Rico EIF systems project appears to be about on par with its seven sister projects sponsored by DOE on the U.S. mainland. Some of its difficulties stem from the delay incurred in relocating its site from the Río Grande poultry farm, and the lack of a project leader since 1983 who is wholly familiar with the Phase I plan for the Juana Díaz site and farming principles in general. The latter issue has been a point of concern both to the farm's owner and the DOE Idaho Operations Office (83, 82).

Recommendations based on the Puerto Rico experience are detailed in a subsequent section; however, EIF systems constraints to date appear to be less in the technical areas of need than in the mobilization of administrative and managerical resources. The University of Puerto Rico's College of Agriculture possesses very talented human resources for the competent management and extension service needs of this project, yet these remain untapped by CEER-UPR. The likelihood of success in implementing authentic EIF systems for U.S. insular areas would appear to be about as good as the leadership that can be brought to bear on specific-site projects.

SCOPE OF ENERGY-INTEGRATED FARMING SYSTEMS

The biological basis for biogas production from manures or other organic matter is a simple, naturally-occurring process. Yet, it has enormous potential for control, elaboration, and efficiency improvement through the intervention of man. It therefore lends itself to a broad scope of applications. These can range from single-household, manually-operated digestors having little in the way of cost or need for efficiency, to huge, costly, corporation-sustaining complexes totally reliant on high technology and having closely-calculated "payback" scenarios that dictate their ultimate success or failure. Rather than dwell on extreme cases, this section considers "small" and "large" EIF systems having realistic potentials for U.S. insular areas.

1. Small-Scale EIF Systems

In considering a small-scale EIF design having meaningful applications in most U.S. insular areas, the following generalized conditions are assumed to apply:

(a) Small, barely-subsistent residence farms or rural households (frequently with the family head employed as day labor on larger farm units) whose livelihood is supplemented by private poultry, swine, cows or goats, and draft animals — or all of these — in limited numbers. Collectable animal wastes would be in the order of 40 to 200 pounds per day.

(b) Animal wastes supplemented by plant residues from private gardens, kitchen refuse, and weed or brush clippings from farm maintenance. Plant material wastes would be in the order of 10 to 50 pounds per day.

(c) An on-going need to improve both household and livestock diets, particularly with supplementary protein at low cost.

(d) Rural electrification already installed, or planned for installation within the foreseeable future.

(c) Compliance obligations for existing EPA legislation, of for environment-protection laws to be enforced within the foreseeable future.

(f) Comparatively high rural literacy (relative to non-U.S. developing areas), and eventual access to agricultural extension and rural sociological services.

Given this generalized scenario, an appropriately inexpensive, small-scale EIF system would incorporate three simple components:

- A manure/wastes collection and blending subsystem
- A biogas production and storage subsystem
- A digestor waste (sludge) utilization subsystem

A flow diagram of the three components is presented in Figure 1. Design emphasis always confines itself to simplicity and low cost. Total expenditures for construction materials, including containers, pipes, tubing, and fittings, should not exceed about 500 to 600 U.S. dollars.

The collection and blending unit might simply consist of a galvanized metal washtub, while treated fuel drums are suitable for digesters. Some simple insulation is gained by partial burying of the digestor, mounding its sides with soil, or encasing in styrofoam or other cheap material. The washtub "blender" enables the unit owner to mix manually small amounts of solid wastes and water, forming a slurry that can be poured manually when reloading the digester. The digester operation itself would be a small-scale "batch" system, with infrequent manual agitation (twice daily), plus emptying of sludge and reloading with fresh slurry at 5-to 10-day intervals. The slurry undergoing anaerobic fermentation in such small units is readily illustrated with a transparent glass container (Figure 2-A), together with the biogas itself emitted as surface bubbles (Figure 2-B).

The digester waste cleanup subsystem is similarly uncomplicated at this scale, but it is a necessary factor in view of environmental awareness in U.S. insular areas. There are potential benefits as well for the small farm operations or rural family. It provides odorless solids for fertilization of gardens. Because of its high content of undigested protein, it can be recycled to cattle and poultry when dried and blended with their regular dry feed rations (4, 41, 9). The solids can be separated from the residual liquids by coarse sieving or merely by gravity separation in a small settling pond designed for periodic draining and cleaning.

The wastewater itself can be used for garden irrigation, or further cleaned by an inexpensive form of "aquaculture" (41, 26, 35, 78, 29). By this means the effluent water is drained to a small pond for propagation of fast-growing tropical fish species that thrive on the suspended organic matter still contained in digester effluent. A species commonly used for this purpose is Tilapia nilotica (Figure 3). The fish themselves can be harvested periodically for food, supplementing the farm household diet (41, 61), or they can be dried and incorporated into cattle feed rations as supplemental protein (4, 3, 5). Mineral components of the wastewater can be eliminated by propagation of fast-growing aqueous plants. A good example is the "water hyacinth" (Figure 4). Variously regarded as an aquatic weed, pest, and attractive ornamental (84, 56, 86, 30), its highly-succulent leaves and stems can be harvested easily and employed as a digester feedstock supplement for additional production of biogas (9, 4). Other candidate water plants include "water lettuce", the "duckweed" (72, 46, 73, 80), and the common "cattail" (74, 63, 15, 5). In some circumstances the production of green algae (41) and higher aquatic weeds (19) could be viable options for wastewater usage.

Options for use of the biogas under these circumstances are constrained by the presence of rural electrification and the relatively small quantities produced. They would not justify the purchase of, and full-time reliance on, a private engine-generator set. Nor is residential heating a major need in the insular tropics. Alternatively, some usage is seen in the heating of water and refrigeration in the rural home kitchen. It has applications in widely-isolated outbuildings. It is useful as a part-time substitute for utility power in the kitchen, and as a backup for both cooking and lighting during periods of power outage. When there is no need for the biogas it is easily vented to the atmosphere (5).

In terms of "social consideration", the opportunities described above for small EIF systems would need to be implemented (in whole or elements thereof) via demonstration farms, and by one-on-one assistance to interested farmers by trained extension agents over a period of decades, to materially improve the quality of life for rural households. As described, costs would be generally low, but specific costs would vary from farm to farm. Within any given farm or household the costs will vary with attitudes and level of interest/commitment of individual owners.

Opportunities for biogas utilization increase with larger-scale EIF systems. These have proportionately larger manure and waste resources to supply a more sophisticated digester. There could be a simple pooling of resources by a number of farm households or a small rural community. Once installed and reliably operational, the engine-generator set could all but eliminate dependence on utility power other than as a hook-up for emergency use. In certain favorable circumstances the hook-up could be used to sell the farm's excess electricity to the utility (5, 4, 3).

2. Large-Scale EIF Systems

"Large" is an extremely intangible term as applied to EIF systems. A 100-head dairy herd would seem enormous to one farmer and scarcely worth its bother to another farmer in U.S. insular circumstances. The terms "industrial" and "commercial scale" are also indefinite. Ironically, the world's largest anaerobic fermenter was designed and constructed in Puerto Rico, by the Bacardí Corporation (79), as a means to recycle rum distillery wastes formerly discharged offshore on the island's Atlantic north coast (Figure 5). Although having several million gallons capacity and costing vast corporate expenditure, it is nonetheless an upscaled application of biogas production and waste-cleanup principles described above for small-scale EIF situations.

A meaningful, large-scale EIF system will require very serious attention to site selection and approval, professional preparation of site-specific designs, and financing of costs with the attendant new obligations to the farm owner. There must be very serious attention to detail in construction engineering, operations maintenance, and close compliance with environmental-protection laws (5, 4). Hence, the following conditions/assumptions are added to those already listed above for small-scale EIF planning in U.S. insular areas:

(a) Sufficient usable space for installation of the necessary EIF components or "subsystems". This was a major concern of the Puerto Rico-DOE EIF project. Eventhough the farm was "large" by insular standards, the subsystems emplacement was physically constrained by unusable steep hillsides, bordering by semi-dry stream beds, close proximity to human residences ("barrios"), and a typically haphazard layout of the original farm components (Figure 6).

(b) Sufficient manure and other farm wastes to sustain an economic production of electricity and energy-related byproducts. This relates also to the prices the farm owner must pay for utility power, his subsidies and tax benefits, and willingness of the utility to buy the excess EIF power at equitable prices. Under Puerto Rico circumstances (utility power at about 12.5 cents/kwh), the minimal manure needs would derive from about 200 head of milking dairy cattle, about 600 head of swine, and about 6,000 birds in a layer poultry farm (5, 41). Also, planners can be easily misled by visible mounds of stored manures and accumulated floor scrapings from feedlots (Figure 7). It is the daily collectable tonnage that is meaningful for digester feedstock computations.

(c) Farmer access to local or Federal financing, plus subsidies/incentives programs that ease the burden of modification to an EIF design.

(d) Farmer access to engineering expertise for EIF systems analysis and design, installation, and maintenance.

(e) Farmer access to agricultural extension or rural sociological expertise, to assist with post-installation teaching, demonstration, and public-awareness activities stemming from the operational EIF.

A critically-decisive factor is the existence of the regional "collaborator" or "leader" type of landowner. He must be willing to accept the inconveniences and costs of having his farm operations disrupted while the first model or demonstration EIF system is installed in his area. Invariably, this man will confront head-on many peculiarities of climate and natural resources, subsystems engineering, designs performances, materials and equipment performance, and administrative bureaucracy. He is the "ice breaker" whose own experiences — good and bad — will serve as instructive lessons for EIF owners to follow.

The Puerto Rico EIF design sponsored by the U.S. Department of Energy[2] is taken as a model "large-scale" EIF experience for U.S. insular areas (5, 4, 3, 9). Its dual themes are integrated-energy and environmental-compliance subsystems. They offer modern, economic, and socially-compatible alternatives for a large, commercial farm operation, heavily pressured by economic and environmental forces that emerged since the mid-1970's (5). The basic design utilized a 500-head dairy farm in a hilly, semi-arid zone. It incorporated eight subsystems; any one or all of these might have advantageous application on neighboring Puerto Rico farms or in other U.S. insular areas. They include:

- A greenfeed subsystem using 10% of the farm's raw manure output for fertilization and soil improvement.
- A collection and blending subsystem for the remaining 90% of recoverable manure.
- Twin anaerobic digestors for biogas recovery and storage.

- A biogas-fueled enginegenerator set for electrical power production and supply to on-farm operations.
- A digester sludge processing subsystem, for separation of wastewater and reusable solids.
- A drying and recycle subsystem for digester solids, to be used as feed supplements for the milking herd.
- A two-lagoon subsystem for cleaning wastewater prior to its reuse in crops irrigation.
- Water storage lagoons, for both cleaned wastewater and surface rainwater runoff, for irrigation and blending with fresh batches of manure.

A flow diagram for these subsystems is presented in Figure 8. Detailed designs and specifications for the EIF biogas production and wastewater cleanup components, approved by DOE staff engineers, are found in the final Phase I and progress reports (4, 3, 10, 46).

The entire complex utilizes the gravity flow created by the farm's hilly location to move materials without the aid of electrically-powered pumps. The only use of a pump envisaged in the original design was for the recycle of cleaned wastewater to a point where it could be utilized in preparing fresh manure/water slurries. A wind-powered pump was indicated for this purpose, thereby employing the northeasterly trade winds which are a natural energy resource of the insular Caribbean Basin (4, 11). Provision was made for monitoring the operational complex of subsystems to assure compliance with Puerto Rico's Environmental Quality Board regulations (5).

Taken together, the EIF design was to provide 30 to 40 percent of the herd's feed requirements and 60 to 80 percent of farm power needs (4, 3, 11). Annual operating costs were estimated at $55,000 and benefits at $151,000. Systems design and installation costs were placed at $582,000. A waste management value of $48,000 was also credited to the integrated designs. As an energy and feed-producing enterprise the EIF "payback" time was estimated at 6.1 years. As an energy, feed, and waste-management system the estimated payback period was reduced to a maximum of 4.1 years.

Certain features of the Puerto Rico EIF design have special importance for U.S. insular areas: (a) Intensive production of greenfeed with a fraction of the farm's raw manure; (b) conservation of water, from all sources; and (c), potentially vast impacts as a teaching/extension mechanism. This farm had relatively little level land, being constrained by hills and adjoining residential areas (Figure 6). Many such farms obtain virtually all of their cattle feed through outside purchases on a year-round basis (83, 66), an absurdity in areas having year-round growing seasons. In the Puerto Rico project, dry manure was distributed on a rotavated seedbed with a single-axle spreader (Figure 9-A) and seeded in a fast-growing tropical forage grass hybrid[3] (Figure 9-B). At 5-to 7-week intervals (6), the grass was cut with a field chopper and the stubble refertilized with manure (Figure 9-C). Such materials are an excellent dietary supplement for lactating cows (2, 38, 64, 85 75). They are much welcomed by animals long accustomed to dry-feed rations (Figure 9-D). A simple principle here is that, when warm temperatures, water, and excess manure can be brought together, it is usually more economic to increase the productivity of small areas of even poor soils than to deal with large acreages having permanent barriers to productivity (14). As illustrated in Figure 10, the landowner can raise tropical grass yields to strikingly high levels by allowing up to 6 months to elapse between harvests. In such instances the grasses may bring greater returns as a salable biomass fuel than as a cattle feed (14, 2, 12).

Water conservation is always important for an efficient EIF system, but doubly important for arid-to semi-arid zones common to Puerto Rico and the U.S. Virgin Islands. This stems from low total annual rainfall, uneven (seasonal) reception of rainfall, and high "pan evaporation" rates, coupled often with landowner ignorance of water-conservation principles.

Key elements of water conservation in the Puerto Rico design include recycle of part of the system's cleaned wastewater for daily preparation of fresh manure/water slurry, and use of the remainder in crops irrigation (6, 4, 9) including the greenfeed subsystem (Figure 9). Storage of water in prepared farm ponds is highly desirable and was a feature of the Puerto Rico dairy farm even before the DOE-EIF project was located there (83, 9). Typical of the Caribbean Basin, the farm at Juana Díaz received heavy rainfall only during a 3-month interval from September to December; moreover, the high pan evaporation rates encouraged by dry, northeasterly winds actually exceed rainfall throughout most of the year (Figure 11). The problem of assuring an adequate water supply for the Juana Díaz dairy farm was alleviated in two ways (6, 9): (a) Storage of excess rainfall by impounding surface run-off (Figure 12-A), and (b), transfer of excess irrigation water from a distant canal to a prepared pond immediately accessable to EIF systems needs (Figure 12-B).

Additional factors to assess for large-scale EIF systems include the following:

(a) Management Structure: Ultimate management of a large-scale EIF system must reside directly with the farm owner and his employees. In a few instances the owner will be a corporation, but in any case a combination of profit incentive, pride of achievement, desire for self-improvement, and willingness to accept the "knocks" of technical mishaps and bureaucratic ineptitude are needed to sustain the EIF systems owner.

The question of management is a decisive feature of the first EIF complex to be introduced to a given area (5). At this point, management should lie in the hands of contracted specialists, with the understanding that they will ratain responsibility for the installed subsystems until they are operating at design specifications. The contractor's responsibilities will include the training of the farm owner in operation and maintenance of the EIF system (7). The contractor himself could be a commercial entity, a university, or even a government office or agency. Involvement of university-trained agricultural/extension personnel would be desireable, particularly as a follow-up to the installation of a first model or "demonstration" EIF system.

(b) Incorporation Of Energy Crops: In most of the developing tropical world, in some 70 countries, the concept of waste management in large EIF systems would lend itself well to sugarcane production as a high-biomass, multiple-products commodity, ie, as "energy cane" (14). However, except for Puerto Rico, there is little in the way of sugar planting in the subject areas, nor is the prospect good today for future expansion of sugar planting anywhere in the tropics (14, 12, 13).

Alternatively, there are excellent opportunities for small-scale production of the "allied" tropical grasses that attend energy cane planting, utilizing the excess manure, waste solids, and cleaned wastewater effluents of large EIF systems (14, 2, 10). Examples are seen in the tropical forage grasses illustrated in Figures 9-C and 10. When dried, such species provide quality "lignocellulose feedstocks", which in turn are renewable, domestic substitutes for the petroleum currently imported by U.S. insular areas

(Figure 13). Their potential applications range from "near-term" boiler fuels (20, 71, 25, 34, 14, 13) and proprietary commercial fuel products (14, 28, 34, 58, 10) to long-term use as feedstocks for synthesis gas and high-value chemicals production (13, 14, 51, 27, 88, 70).

(c) EIFS Materials Transportation: Because of their high moisture content and dispersal, manures and other wastes used in EIF systems do not lend themselves well to handling, loading, transloading, and long-distance transport. System designs will emphasize minimal hauling and handling, if possible with a tractor-mounted loader operating on a concrete surface to assist manure separation from the underlying soil. Where possible, gravity flow of materials through installed subsurface tubes is highly desired; this was a consistent goal of the Puerto Rico EIF design (4, 6, 9), and guided materially the author's selection of the Juana Díaz site.

(d) Availability of Information, Management, Labor: This issue is touched upon repeatedly and deserves reemphasis. The conception, design, and installation of a large-scale EIF system is beyond the usual capabilities of the farm owner (5). Labor should be no problem, but expertise in design engineering and agricultural integration of the unfamiliar new systems will need to be hired. If unavailable locally, this expertise can be "imported" from the U.S. mainland or the State of Hawaii. The atypical costs of such an EIF system should be justified if viewed as a model from which local talent can be drawn and many additional EIF units established. Assistance from Federal or local government agencies, universities, and agricultural colleges will likely be needed in any case to establish the first demonstration farm.

POTENTIAL OF ENERGY-INTEGRATED FARMING SYSTEMS

At this point in time, there appears to be a vast but variably-perceived potential for EIF systems development and implementation in the U.S. insular areas (5, 32, 22, 23, 31, 36). As in the foregoing assessments, these potentials are pegged to the scale of development to be undertaken and site-specific opportunities for doing so.

1. Small-Scale EIF Systems

Without question, there is genuine need and potential for EIF systems implementation at the level of the small farm and rural household of developing insular areas. Such implementation is encouraged by the following:

- Simplicity of EIF systems at this scale
- Low cost of EIF systems at this scale
- Favorable climate and waste-resource conditions
- Need for economic and dietary upscaling of rural households
- Need for environment preservation in U.S.-controlled areas
- Available technology for implementation

It is important not to confuse the small but beneficial EIF concepts with larger-scale systems having special needs for financing, engineering, and operating-management skills. For the most part, the small-scale EIF system will offer improved management of water and waste resources, improved productivity of the owner's few animals and his home gardens, and some cutbacks in his costs of cooking and of heating water. These are issues with which he is already familiar to some degree in any case. They are not a large technological assault on an electrical power bill, as large EIF systems often appear to be (5, 41).

In this context the small-scale EIF design can benefit populations of all the U.S. insular areas, whether widely-dispersed or centrally-located. Even in Puerto Rico, aside from the more cosmopolitan segments of San Juan and Ponce, a large percentage of the insular population could still benefit from EIF elements applied at the back-yard, private-garden, and private fishpond level (5, 41).

2. Large-Scale EIFS Systems

Opportunities definitely exist for implementation of large-scale EIF systems in U.S. insular areas (5, 4, 11). As noted earlier (79), the largest commercial application of energy from biological wastes technology was recently installed by the Bacardí Corporation in Puerto Rico (Figure 5). This is merely a very large application of the same biogas production principles that pertain to the simplest small-scale household units already discussed for rural insular areas. However, three constraints appear to operate against long-term attainment of the larger EIF designs on anything like the massive implementation foreseen for small-scale systems: (a) Relative lack of genuinely large cattle farms (over 500 head) and poultry farms (over 6,000 birds) producing appreciable daily tonnages of recoverable manure; (b) relative lack of expertise for design, installation, and operation of large-scale EIF systems; and (c), wide dispersal of suitable EIF sites among U.S. insular areas (22, 23, 31, 36).

The latter constraint, insular site dispersal, is the most serious. Even in the developed continental U.S., the establishment of seven regional demonstration farms, each completely accessible for hundreds of miles by well-developed expressways, has yet to prove itself as a meaningful aid to needy U.S. farmers as a whole. Perhaps this is an insurmountable issue in the "real world" of landowners just too busy and burdened with other cares to drive a hundred miles or more to study systems they don't comprehend. In this author's opinion, a well-designed, operational EIF system in Puerto Rico might as well be located on the moon insofar as any fluent exchange with Pacific Basin farmers is concerned. An obvious answer to this constraint is Federal government intervention in bearing the costs of an exceptionally comprehensive program for inter-island and inter-regional teaching and extension services.

Further definition of the opportunities for large-scale EIF systems will require island-and site-specific surveys of EIF resources and constraints. In addition to the three limiting factors noted above (manure supply, expertise, and geographic dispersal) the survey teams will need to address mechanisms for EIF financing, attitudes of the local populace, ability of local institutions to "package" and "sell" their EIF opportunities, and collaboration of agricultural and industrial enterprise (i.e., "twin plant" operations in the CBI context).

RESEARCH AND EXTENSION

In very general terms it can be said that EIF systems research is needed and can be beneficial to U.S. insular areas. Research on biogas production from wastes via anaerobic fermentation is in fact progressing at both the academic and private-industrial levels (5, 45, 39, 57, 84). A good example of this is the "anaerobic filter" design that was created, perfected, and upscaled to commercial application by the Bacardi Corporation, thereby meeting their private needs for distillery waste disposal (79). Similarly, each of the DOE-sponsored EIF projects on the U.S. mainland engaged in some level of academic research relative to components performance in their specific designs.

It would be difficult to outline succinctly a blanket EIF research program that would simultaneously benefit all U.S. insular areas (5, 22, 36). Two broad types of research would be beneficial, particularly for intermediate-and large-scale EIF applications: (a), Individual components testing and perfection for subsystems still under design or installation at specific EIF sites; and (b), solution of operational problems that arise, or become evident for the first time, after an EIF system has been installed and operated at its original design specifications. An example of the first type of research need is the maximizing of efficiency of biogas recovery from the site-specific manure resources. An example of the second type of need is the failure of materials used in components construction (ie, a fiberglass digester cover, or a rubber gasket for sealing the cover, giving excellent performance in Minnesota, might fail in the continuous heat of the tropics). Obviously, such research issues are of less importance in the small, household-level systems where efficiency was never an objective and inexpensive materials are virtually mandatory.

The importance of extension services has already been noted repeatedly. More so than in the design and installation of EIF systems, which in any case is primarily the responsibility of engineers, the long-term benefits of operational "demonstration" EIF projects require the input of extension professionals skilled in communicating with agrarian populations having minimal technological background (6, 9).

At least in theory, the agricultural extension personnel of mainland State Universities (Hatch-Act colleges, "cow colleges"), together with their administrative structures and rural sociological programs, appear to be well qualified to deal with EIF systems establishment among rural people. Extension services for the U.S. insular areas could well be modeled after the U.S. mainland experience in extension.

Based on Puerto Rico's experience, it appears that special care must be taken at higher administrative levels to assure that qualified personnel are actually made available for energy-oriented extension activities. Some difficulties encountered here have already been noted in the Introduction to this assessment. For project leadership, the procurement of a qualified leader can be very difficult and ultimately decisive. For the truly demonstrative project in tropical insular areas, the scope of necessry technical understanding is indeed broad, including at least solid appreciation of tropical botany, biology, agronomy, agricultural engineering, livestock management, farm accounting, rural sociology, and other disciplines, coupled with tolerance of government bureaucracy.

The potential problems in gaining commitment of existing technical services are not entirely bureaucratic. There has been a slowness, or unwillingness, among influencial policy makers to accept the recognition of energy per se as a renewable domestic farm resource, or the planting of biomass energy as a valid agricultural activity (14, chapter 16). Under these circumstances, energy-oriented activities are confined to limited-term projects funded by outside grants and play no role in the state-funded programs for permanent farm commodities. In the case of EIF systems development for all U.S. insular areas, energy is most definitely a farm commodity and one of long-term importance. It should be identified as such at the onset at the highest administrative levels.

SUMMARY: OPPORTUNITIES AND CONSTRAINTS

1. Major Opportunities And Benefits

Implementation of EIF concepts in the U.S. insular areas, particularly at the small- and intermediate-scale levels discussed above, would permanently benefit these areas in both abstract social/economic ways and in technical/legal aspects of their future development. These include:

- A material shift from reliance on imported fossil energy toward utilization of renewable domestic energy.
- Reduction in dollar "leakage" from the insular economies.
- Expansion of the industrial feedstocks base (lignocellulose).
- Creation of new cash crops for supplemental farm income.
- Dietary improvements for small-farm and rural households.
- Improved diets and productivity of livestock.
- Improved productivity of farm soils and household gardens.
- Improved conservation of rainfall and recycled farm water.
- Improved quality of surface and ground-water resources.
- Legal compliance with environmental legislation.
- Elimination of potential sources of disease and health hazards.
- Improvement and preservation of ecosystems quality.

If means can be found to implement elements of energy-integrated farming, eventhough it might require a generation or more to do so, such benefits would be real for insular areas and not mere glittering generalities. Yet, the implementation issue is a difficult, multi-dimensional one having educational facets as well as the social/technical/economic ones already discussed (22, 23). For example, the small farmer involvement in producing lignocellulose feedstocks for future insular petrochemicals industry, to compliment still-hazy plans for marine and forest biomass development, has not ordinarily been treated in planning the purely biogas-from-manure systems of existing EIF designs (60, 81, 50, 5, 7, 77).

The possible social/financial "costs" of EIF implementation can be stated in broad terms regardless of the non-homogeneous and geographic dispersal of US insular areas. Financially, it would be disastrous to force EIF concepts on developing societies even within a "blank check" scenario. A parallel illustration is found in Puerto Rico's ill-advised attempt to replace sugarcane with rice. Between 1977 and 1984, some $42,000,000 were spent to establish only 1,960 acres of rice, at a cost exceeding $21,000 per acre. The PR farmer simply didn't know how to grow rice and the Government didn't know how to help him. The social "cost" of EIF implementation is found in well-planned teaching and extension programs conducted over a long period of time, that is, at least one generation (25 years) and very likely two generations. In the author's opinion, the developing insular farmer is neither stupid nor lacking of industry, but he must first be respected then taught and guided as a long-term effort. Finally, the ultimate cost of eventual increased affluence (if Puerto Rico's example is to be believed) could be the substitution of solid family and religious virtues by increasing crime rate, use of drugs, loss of self identity, and reliance on "the government" to solve life's special problems.

2. Role Of U.S. Federal Policies, Programs Regulations

Implementation of EIF systems in U.S. insular areas would involve the U.S. Federal Government both directly and indirectly. As noted earlier, the evolution of U.S. mainland attitudes toward natural resources, the environment, environmental protection, and legislated mechanisms to enforce environmental protection, have created significant constraints in costs and implementation time for EIF concepts. Similarly, the need for EIF systems that are "environmental-compliance" as well as "energy-integrated" can increase materially the long-term opportunities and benefits of EIF systems; it is in this context that the EIF concept moves a whole dimension beyond that of mere reaction to excessive OPEC oil prices (41, 5, 1).

It has already been pointed out in discussion of the DOE-sponsored project for Puerto Rico that a well-designed EIF complex of mutually-supporting energy/environment subsystems can return a disproportionately large increase of benefits to the farmer, some of them offering means for long-term profit making unheard of prior to the 1974 petroleum embargo (5). The role of U.S. Federal policies should be seen as one of overall encouragement toward these ends within acceptable interim guidelines. For example, the massive closing down of Puerto Rican farms through enforcement of existing laws would merely create still greater problems, while terminating most ongoing efforts that can lead to full compliance and a vastly improved rural economy (5, 83, 4, 76).

It is important that future policy makers do not consider the U.S. insular areas as a logical single "package", as the OTA assessment seems prepared to do. The latter is not a wise perception either for planning and policy purposes or for technical ones. Aside from the severe constraints of geographic dispersal already discussed, the U.S. insular areas are components of the Pacific Basin on one hand and the Caribbean Basin on the other. Each is distinguished by discrete prehistoric, historic, cultural, social, political and economic forces of development (62, 22, 21, 31, 36). Even climatic distinctions are greater than generally appreciated (5, 3, 22, 42).

The following suggestions are offered in regrouping the U.S. insular areas for future policy considerations:

(a) Treatment of Puerto Rico and the U.S. Virgin Islands as "sister" communities, having the existing DOE-sponsored EIF project and research/extension expertise of institutions based in Puerto Rico and the Virgin Islands as focal points of departure for future development.

(b) Treatment of the Pacific insular areas as a separate group, having as their focal point a Hawaiian technical institution, ie, such as the HNEI (Hawaii Natural Energy Institute, University of Hawaii). Similarly, the UH College of Agriculture's research and extension services could contribute to the development of Pacific area EIF systems.

With specific reference to Puerto Rico and the U.S. Virgin Islands, Federal planners should note the possible advantages of EIF systems development as an element of the Caribbean Basin Initiative (CBI). As broadly perceived, CBI would promote stability and economic progress among all Caribbean-area nations. Both direct and indirect economic assistance would be provided, as for example in the easing of import restrictions on goods from participating non-U.S. countries. The latter feature is seen by some analysts as a setback for U.S. areas already enjoying special arrangements with the U.S. government (ie, rebate of Federal rum taxes to the Puerto Rico treasury, and "section 936" tax incentives for manufacturers locating in Puerto Rico[4], are examples of currently-sensitive issues). In the case of rum manufacturing the implementation of CBI would erode the near dominance of the U.S. mainland market presently enjoyed by Puerto Rico distillers.

Altenatively, implementation of novel new features of CBI development planning, such as the "twin plant" concept, should aid materially the growth of EIF based industry. Conceptually, twin-plant industry would utilize less developed areas as sources of raw materials, or of partially-complete manufacturing components from low-cost labor, while completion of the manufacturing process would proceed at a second factory site employing higher-cost labor and technology (44, 68, 55).

An example of EIF benefits from twin-plant industry is illustrated schematically in Figure 14. Lignocellulose produced with EIF-derived manures, wastewater, and digester-sludge nutrients, and unprocessed except for drying and size reduction to minimize transportation costs, would be shipped to a centralized, high-technology processor for conversion to synthesis gas. As a domestic feedstock substitute for natural gas, the synthesis gas can be used to manufacture many upgraded products more generally known as "petrochemicals" (58, 69, 70, 87). However, in Figure 14 the synthesis gas is directed to production of nitrogenous fertilizers through known technology. These are utilized by insular agriculture as relatively inexpensive substitutes for the imported, high-cost (and highly energy-consumptive) commercial-N fertilizers presently available at nearly prohibitive prices (13, 14, 65, 53, 67). A typical EIF lignocellulose product could be the napier grass illustrated in Figure 10, with its solar-dried and size-reduced form shown in Figure 13 becoming the base feedstock for the "second-plant" operations.

3. Appropriate Objectives For Congressional Action

Only general suggestions can be offered here because only congress can identify specifically what it wants from and for the U.S. insular areas.

It has been argued recently in scholarly fashion (62) that in 86 years Congress has not been entirely clear on these two points even for so visible an issue as Puerto Rico and its permanent form of sovereignty.

With reference to EIF systems implementation, their obvious improvement of insular social and economic welfare, together with the political stability that accompanies such improvements, would indicate a need for solid support from Congress. To this end the following suggestions are offered:

(a) Environment Legislation: Postpone or desist entirely from enacting more laws in the name of "environment preservation". As noted previously, Puerto Rico has more environment-oriented laws than the average farmer can comprehend, not to say accommodate, at this time. In the enforcement of existing legislation, recognize the need of time (perhaps a generation) for rural insular populations to learn technologies of farm waste management. Timetables for the latter are vastly more complicated than those for removal of lead from motor fuels.

(b) Economic Support (R & D): Federal funding for biogas production systems design and performance R & D under tropical conditions would pay disproportionately large returns. Two regional projects, in correct technical and administrative hands, would suffice, at a level of $300,000 to $400,000 per annum.

(c) Economic Support (Implementation): Long-term financing, favorable interest rates, and guarantees by the Federal Land Bank or comparable institution, would attract the progressive farmer.

(d) Incentives And Subsidies: Tax incentives are advisable for collaborating EIF owners (regional demonstration) and follow-on independent farmers, and subsidies for production and sale of EIF subsystems commodities (electricity, feeds, lignocellulose).

(e) Administrative Organization: Manage Federal inputs to U.S. insular areas via separate Caribbean Basin and Pacific Basin offices. At the field level, neither private-industrial nor academic institutions have been wholly successful in managing EIF projects. However, prior experience and expertise already exist at DOE, University of Puerto Rico, and HNEI (University of Hawaii). Its reinvestment could save time and the reinvention of many EIF wheels.

(f) Federal Tax Code: There is genuine need for correctly-designed EIF systems to direct their lignocellulose products to manufacturer feedstock bases. Hence, EIF development would be served by retention of Section 936 tax incentives for manufacturing in the new Federal Tax Code.

4. Other Institution Roles On Behalf Of Insular EIF

(a) U.S. Federal Government Agencies: As noted elsewhere in this assessment, the U.S. Department of Energy has significant prior experience in establishing and monitoring regional EIF projects. DOE should have a role in future insular area EIF work as well. The U.S. Department of Agriculture (USDA) and the USDA Soil Conservation Service (SCS) could contribute important technical assistance, as was the case in Puerto Rico's EIF project (wastewater and aquaculture subsystems analysis and implementation).

Although some U.S. insular areas have international and developing-nation characteristics, the U.S. Agency For International Development (AID) probably should not be called upon. The AID record in implementing biomass energy projects abroad is poor, nor is there existing AID expertise in EIF systems design, analysis, and implementation. From the Puerto Rican point of view, AID consists mainly of talk and bureaucracy with little action. The author's experience with AID tends to sustain this image.

(b) Insular Governments: Decisive contributions can be made at the local government level. Direct support through matching of Federal grant funds would be desirable. Indirect financial support is possible, as for example the allowance to EIF owners the same incentives and subsidies already provided for conventional farm commodities and operations. As noted elsewhere in this assessment, local governments might not perceive energy production as a valid farm activity (14, 34). An interim easing of local environment-law enforcement by the insular EPA counterparts can assist materially the installation of compliance EIF facilities (5, 83). In the longer-term, insular government intervention on behalf of preserving a favorable U.S. Federal tax code (Section 936 for Puerto Rico) would hasten the integration of EIF and manufacturing industry. In Puerto Rico's case, the Chief Executive has given this his personal attention both in Washington and Puerto Rico.

It would be well also if local governments could separate EIF related issues from partisan politics, as has happened with Section 936 issues in Puerto Rico (68). Local government roles are also seen in establishing equitable rates and conditions for sale of excess EIF power, in establishing formulas for computing avoided costs to the EIF owner and rural households, and for making accessible to the local farm level such Federal programs, incentives, and regulations that originate in Washington.

(c) Private Industries: Aside form a few striking examples, such as the Bacardī "anaerobic filter" system for rum distillery wastes conversion to biogas, private industry participation in EIF implementation remains largely an untapped resource. In theory, insular organizations such as professional dairymen and poultrymen associations have sufficient stake in EIF technology for them to get seriously involved. This has not happened; rather, a "wait and see" attitude appears to prevail.

(d) Academic Institutions: These appear indispensible for both EIF research and systems implementation in U.S. insular areas. Their roles have been discussed repeatedly in this assessment. Divisions of the University of Puerto Rico and University of Hawaii are already indicated for development of EIF technology in the Caribbean Basin and Pacific Basin, respectively.

(e) Non-Profit And International Organizations: Very limited contributions, if any, are foreseen in implementing EIF systems for U.S. insular areas.

5. Forecast Of EIF Effects And Consequences:

Development of EIF technologies is expected to produce some striking and relatively near-term benefits (5-7 years), but these will affect a comparatively few farmers having existing large manure supplies and pressing need for its disposal. In the longer-term (8-20 years), smaller and less spectacular impacts could be produced by small-farm and household-level biogas units implemented on a massive scale. Benefits of the latter would be permanent and contribute to the general welfare of the insular community.

It is doubtful whether EIF technology will in itself produce large reductions in the expenditures for imported petroleum. Its long-term impacts will be felt as one component of a renewable energy technologies "package" that must include marine and forestry biomass, solar and wind technologies, and possibly ocean thermal (OTEC) and wave-action systems as well. Final perfection of such packages will require considerable tailoring to specific insular situations; some 30 to 40 years might well be needed to attain such levels of independence from imported fossil energy.

While anaerobic fermentation will ordinarily be a key feature of insular EIF systems, the biogas products and byproducts will improve insular welfare in many ways, both direct and subtle. In the larger installations there will be direct substitution of purchased utility power and periodic sales of excess EIF power to local utilities. Indirect substitution will occur in the recycle of mineral nutrients contained in the digester solids and wastewater, in protein recycle to farm animal feed rations, in imported dry-feeds and feed-concentrates substitution with greenfeed, and on-farm production of plants and fish in EIF aquaculture subsystems. The efficiency of farm resources utilization would be improved (48, 16), while even the smallest of EIF systems can improve household diets, increase yield from private gardens, and increase productivity of household cows, poultry, swine, and draft animals. At all levels of scale, EIF technology will increase compliance with environment-protection laws and guidelines (4,3,73,24).

It is believed that EIF technology implementation will be slower and more frustrating than is technically necessary. Quite aside from the vast geographic dispersal of these areas, there will not be sufficient funding, trained technologists, and incentives to do so[5]. This is underscored by the recent DOE-EIF program on the U.S. mainland and Puerto Rico. Even well-screened, well-funded, and tightly-monitored projects gained less than highest marks, with time delays, cost overruns, and failure of subsystems to perform at design specifications being commonplace.

Alternatively, much can be gained for future EIF insular programs at the non-technical administrative level. Inadequate administrative mechanisms sometimes prevented the best available talent from becoming involved in Puerto Rico's DOE-EIF activities. As stated earlier, likelihood of success in implementing authentic EIF systems for U.S. insular areas would appear to be about as good as the leadership that can be brought to bear on specific-site projects.

REFERENCES

1. Agee, D.,"Waste Disposal A Threat To P.R. Economic Growth", *Cribbean Caribbean Business* 13(26): 19, July 6, 1985.

2. Alexander, A. G., "Management of Tropical Grasses As A Year-Round Alternative Energy Source". Proceedings IGT Symposium: *Energy From Biomass And Wastes* 5:87-104; Orlando, Florida, January 26-30, 1981.

3. Alexander, A. G., et al., *Systems Analysis And Design Of An Energy Integrated Tropical Dairy Farm*, Phase I Report, DOE Contract No. DE-FCOOL-80CS-40376, Janaury 15, 1982.

4. Alexander, A. G., et al., *Systems Analysis And Design Of An Energy Integrated Tropical Dairy Farm*, Phase I Final Report (Revised), DOE Contract No. DE-FC001-80CS-40376, June 15, 1982.

5. Alexander, A. G., "Energy-Integrated Farm Plan for Puerto Rico", UPADI-82 Conference, San Juan, P.R., August 1-7, 1982.

6. Alexander, A. G., et al., *Systems Design and Installation of an Energy Integrated Tropical Dairy Farm*, Progress Report to the U.S. Department of Energy, Idaho Operations Office. Contract No. DE-FC001-80CS-40376, September 15 — October 15, 1982.

7. Alexander, A. G., "Tropical Biomass: A Resource For All Seasons" Symposium Proceedings: *Fuels And Feedstocks From Tropical Biomass II*. Caribe Hilton Hotel, San Juan, P.R., April 26-28, 1982.

8. Alexander, A. G., et al., *Systems Analysis and Design of an Energy-Integrated Tropical Dairy Farm*. Progress report to the U.S. Department of Energy, Idaho Operations Office, Contract No. DE-FC001-80CS-40376, Regional meeting, Lincoln, Nebraska, May, 1982.

9. Alexander, A. G., et. al., Systems Design And Installation Of An Energy-Integrated Tropical Dairy Farm. Phase I supplement and progress report to the U.S. Department of Energy, Idaho Operations Office, Contract No DE-FC001-80CS-40376, Regional meeting, Ithaca, N.Y., October, 1982.

10. Alexander, A. G., "Biomass as a Multiple-Function Natural Resource for Puerto Rico", Tenth Symposium Of Natural Resources, Commonwealth of Puerto Rico, Department of Natural Resources, San Juan, P.R., December 7, 1983.

11. Alexander, A. G., Systems Design And Installation Of An Energy Integrated Tropical Dairy Farm, Progress and status report for Phase II, May 18, 1983.

12. Alexander, A. G., "Energy Cane as a Multiple-Products Alternative", Conference handout, Pacific Basin Biofuel Workshop, Hawaii Natural Energy Institute, Sheraton Makaha Hotel, Oahu, Hawaii, November 1 & 2, 1984.

13. Alexander, A. G., "New Alternatives for Sugarcane Utilization", Proceedings Puerto Rico Sugar Technologist Annual Meeting, Rio Piedras, P.R., December 7, 1984.

14. Alexander, A. G., The Energy Cane Alternative, Elsevier Science Publishers, Amsterdam, 508 pp., 1985.

15. Andrews, N. J., and Pratt, D. C.,"Energy Potential of Cattails (Typha spp.) and Productivity in Managed Stands", J. Minn. Acad. Sci. 44 (2): 5-8, 1978.

16. Anonymous, Agricultural Production Efficiency, U.S. National Academy of Sciences, National Research Council, Committee on Agricultural Production Efficiency, Printing and Publishing Office, Washington, D. C., 199 pp., 1975.

17. Anonymous, Livestock Waste Facilities Handbook, First Edition, MWPS-18, July, 1975.

18. Anonymous, Microbial Processes: Promising Technologies For Developing Countries, Report of Ad-Hoc Panel of the Advisory Committee on Technical Innovation, Board on Science and Technology for International Development, U.S. National Academy of Sciences, Washington, D. C., 1979.

19. Anonymous, Making Aquatic Weeds Useful: Some Perspectives For Developing Countries, U.S. National Academy of Sciences, Washington, D. C., 174 pp., 1976.

20. Anonymous, Bagasse Fired Boilers, Combustion Engineering, Inc., Windsor, Connecticut, 1980.

21. Anonymous, Conference Proceedings: Conference On Energy Planning And Implementation In The U.S. Insular Areas, U.S. Government Printing Office, Washington, 1983.

22. Anonymous, Energy Planning And Implementation In The U.S. Insular Areas: Problems And Policy Options, with Recommendations by the Staff of the Committee on Interior and Insular Affairs, U.S. House of Representatives, Committee Print No. 5, Ninety Eighth Congress, Second Session, May, 1984.

23. Anonymous, "Workshop Reports", in: Energy Planning And Implementation In The U.S. Insular Areas: Problems And Policy Options; Committee Print No. 5, pp. 99-105, 1984.

24. Anonymous, "Growing Hybrid Poplars for Municipal Sewage Sludge Composting", Frysville Hybrid Poplars, Miles W. Fry & Son, Inc., Ephrata, PA, p. 9, 1984.

25. Anonymous, C-E Field Erected Stoker Fired Boilers For Cellulose Fuels, Publication No. PSG-4517, Combustion Engineering, Inc., Windsor, Connecticut, 19 pp., 1978.

26. Bard, J., et al., Handbook Of Tropical Fish Culture, Centre Technique Forestier Tropical, Nogent-Sur-Marne, France, 1976.

27. Baker, E. G., Mudge, L. K., and Brown, D.M., "Methanol and Ammonia From Biomass", Chemical Engineering Proceedings, December, 1984, pp. 43-46.

28. Beningson, H. E., "Development of Free-Flowing Powder Fuels From Biomass", Symposium Proceedings: Fuels And Feedstocks From Tropical Biomass II, Caribe Hilton Hotel, San Juan, P.R., April 26-28, 1982.

29. Behrends, L. L.,"Recycling Livestock Wastes Via Fish Culture," Aquaculture, p. 38, Nov.-Dec. issue, 1980.

30. Boyd, C. E.,"Vascular Aquatic Plants for Mineral Nutrinet Removal From Polluted Waters," Econ. Bot. 24: 95-103, 1970.

31. Brewbaker, J. L., and MacDicken, K. G. (Editors), Biomass Energy Options For The American Territories Of The Pacific, Prepared by the Saipan Workshop Panel, University of Hawaii, 73 pp., November, 1982.

32. Brown, E. E., World Fish Farming; Cultivation and Economics, AVI Publishing Co., Inc., 397 pp., 1977.

33. Bonnet, J. A., "The Quest for Energy Self-Sufficiency in Puerto Rico", in: Energy Planning And Implementation In The U.S. Insular Areas: Problems And Policy Options, Committee Print No. 5, Ninety Eighth Congress, Second Session, U.S. Government Printing Office, pp. 259-279, May, 1984.

34. Bungay, H. R., Energy: The Biomass Option, John Wiley & Sons, Inc., New York, 471 pp., 1981.

35. Brown, E. E., and Gratzek, J. B., Fish Farming Handbook, AVI Publishing Co., Inc., 391 pp., 1980.

36. Case, C. W. and Schaller, D. A., "Appropriate Energy Technology in the U.S. Pacific Territories," Solar Law Reporter 2(6), 1981 (Reprinted in: "Energy Planning And Implementation In The U.S. Insular Areas", U.S. House Of Representatives, Committee Print No. 5, pp. 519-538, 1984).

37. Clark, J. W., Viessman, W. (Jr.), and Hammer, M. J., Water Supply And Pollution Control, Third Edition, Harper & Row, New York, 435 pp., 1977.

38. Ensminger, M. E., Animal Science, Second Edition, The Interstate Printers and Publishers, Danville, Ill., 1951.

39. Easterly, J., "A Survey of Projects Using Biomass as a Fuel to Produce Electricity in the United States", Eleventh Energy Technology Conference & Exposition, Sheraton Washington Hotel, Washington, D. C., March 19-21, 1984.

40. El-Gohary, F., and F. Nasr, "Bicoversion of Organic Waste", Fourth Miami Conference On Alternative Energy Sources, Miami Beach, Florida, p. 318, December 14-16, 1981.

41. Erdman, M. D., Design, Construction, And Demonstration Of An Energy Intergrated Pullet And Egg Producing Poultry Farm. Vol. 1, Technical Proposal to the U.S. Department of Energy, Program Opportunity Notice for Energy Integrated Farm Systems, 97 pp., 1979.

42. Ewel, J. J., and Whitmore, J. L., Ecological Life Zones Of Puerto Rico And The U.S. Virgin Islands, USDA Forest Service, Institute of Tropical Forestry, Río Piedras, P.R., 1973.

43. Fetter, C. W., Sloey, W. E., and Spangler, F. L.,"Potential Replacement of Septic Drain Fields by Artificial Marsh Wastewater Treatment Systems." Groundwater 14:396-402, 1976.

44. Fridman, H. L., "In-Depth Study Sees Economy Decimated if 936 Goes", The San Juan Star, p.30, July 4, 1985.

45. Ghosh, S.,"Net Energy Production in Anaerobic Digestion," Proceedings IGT Symposium: Energy From Biomass And Wastes, 5:253-74, Orlando, Fl. January 26-30, 1981.

46. Hillman, W. S., and D. D. Culley, Jr.,"The Uses of Duckweed," Amer. Sci. 66(4):442-51, 1978.

47. Homick, S. B., "Use of Organic Residue in the Regeneration of Marginal Lands, "Conference Proceedings: Rehabilitation Of Agricultural Lands, Kensington Town Hall, London, March 13-16, 1984.

48. Heichel, G. H., Comparative Efficiency Of Energy Use In Crop Production, Connecticut Agricultural Experiment Station Bulletin No. 739, 26 pp. 1973.

49. Itakura, T., "Methane Fermentation System in Agricultural and Livestock Wastes", Fourth Miami Conference On Alternative Energy Sources, Miami Beach, Florida, p. 317. December 14-16, 1981.

50. Kahnt, G., and Leible, L., "Planting and Cultivating Annual Lignocelluloses", (in German), Abstract in: *Energy From Biomass*, DOE Office of Scientific and Technical Information, Oak Ridge, Tennessee, p. 1, June 30, 1985.

51. Klass, D. L., "Organic Chemical Synthesis", *YearbookOf Science And Technology* (1980), McGraw-Hill Book Co., pp. 302-306, 1980.

52. Kremer, F. V., and Fradkin, L., Bacterial Adaptation to an Industrial Wastewater, Proceedings IGT Symposium: *Energy From Biomass And Wastes*, 5:275-294, Orlando, Fl., January 26-30, 1981.

53. Kroontje, W., "Utilization of Biofuel Byproducts as Fertilizer", Final Report, Contract No. FG43-81R308102, Abstract in: *Energy From Biomass*, DOE Office of Scientific and Technical Information, Oak Ridge, Tennessee, p. 5, June 30, 1985.

54. Kartchner, C. B., "The New Agribusiness 'Gold Rush' in Saudi Arabia", *Agribusiness Reporter* 5(3): 1,4-6, 1984.

55. Konstant, E., "U.S. Firms Look Elsewhere In Case 936 Disappears". *Caribbean Business* 13(26): 19, July 6, 1985.

56. Lee, C., and McKim, T., "Water Hyacinth Wastewater Treatment System", Proceedings IGT Symposium: *Energy From Biomass And Wastes*, 5:59, 1981.

57. Lizdas, D. J., and Coe, W. B., "Operation of a Full-Scale, Integrated Manure Anaerobic Fermentation Facility," Proceedings IGT Symposium: *Energy From Biomass And Wastes*, 5:359-382, Orlando, Fl., January 26-30, 1981.

58. Lipinsky, E. S., and Jenkins, D. M., "Chemicals From Tropical Biomass", Symposium Proceedings: *Fuels And Feedstocks From Tropical Biomass* II, Caribe Hilton Hotel, San Juan, P.R., April 26-28, 1982.

59. Lidin, H., "Manure-Powered Farm Saving 40% in Electricity", *The San Juan Star* p. 14, March 31, 1985.

60. Lockeretz, W. (Editor), "Non-Depletable Energy Sources" (Relevant Section of Six Papers), in: *Agriculture And Energy*, Academic Press, New York, N. Y., pp. 455-535, 1977.

61. McGinty, A. S., "Aquaculture Specialist, Fish Genetics, UPR Department Of Marine Sciences, Mayaguez, P.R.", Personal Communication, June, 1985. Phone (809) 834-4040, Ext. 3439.

62. Morales Carrión, A., Puerto Rico: A Political And Cultural History, W. W. Norton & Co., Inc. New York, 384 pp., 1983.

63. Morton, J. F.,"Cattails (*Typha* spp.); Weed Problem or Potential Crop," Econ. Bot. 29:7-29, 1975.

64. Morrison, F. B., Livestock Feeds And Feeding: A Handbook For The Student And Stockman, Twenty-First Edition, The Morrison Publishing Company, Ithaca, N. Y., 485 pp., 1951.

65. Morell de Ramírez, L., "Project for Evaluation of Herbaceous and Woody Biomass in Compost Production From Mayaguez Municipal Sludge", UPR Department of Chemical Engineering, Mayaguez Campus, Personal Communication, March, 1985.

66. Morell, E., "Director, Federación Pecuarias de Puerto Rico", Personal Communication, March, 1985, Phone: (809) 834-9191.

67. Nagar, B. R., "Alternative to Energy Intensive Fertilizers: Organic Materials", in: Agriculture And Energy, W. Lockeretz (Ed.), Academic Press, New York, N. Y., pp. 657-668, 1977.

68. O'neil, J., "Ferre Says 'United Front' with PDP To Defend 936 In D.C. Has Ended". Headline and lead article, The San Juan Star 136:1. July 5, 1985 issue.

69. Parker, H., "Expectations for Organic Chemicals and Polymers From Biomass Feedstocks", in: Bioresources For Development, Pergamon Press, New York, pp. 290-304, 1978.

70. Pruett, R. L., "Synthesis Gas: A Raw Material for Industrial Chemicals", Science 211:11-16, 1981.

71. Pollock, W. H., Supplementing Coal With Solid Waste Fuels, Publication No. TIS-6504, Combustion Engineering, Inc., Windsor, Connecticut, 12 pp., 1980.

72. Rusoff, L. L., "Duckweed, a Potential Feedstuff for Cattle and Man", Bayou Dairyman, pp. 14-15, January, 1980.

73. Rusoff, L. L., Blackeney, E. W., Jr., and Culley, D. D., Jr., "Duckweeds (Lemnaceae Family): A Potential Source of Protein and Amino Acids", *J. Agric. Food Chem*. 28:848-50, 1980.

74. Reed, C., and Marsh, L. C.,"The Cattail Potential," *Chemurigic Digest* 14:9, 1955.

75. Randel, P.F., Sanfiorenzo, J. H., Vélez Santiago, J., and Carlo, I., *Evaluation Of Several Stocking Rates And Programs Of Suppemental Feeding For Rearing Replacement Dairy Heifers On Intensively Managed Pastures*, University of Puerto Rico, Agricultural Experiment Station Bulletin No. 275, 37 pp., 1985.

76. Shahabashi, J., "Agricultural Engineer, UPR Department of Agricultural Engineering, Mayaguez, P.R.", Personal Communication, June, 1985. Phone (809) 834-4040.

77. Skrinde, R., *AID Priorities For Research In Fuelwood Conversion And Use In Developing Countries*, Report to the United States Agency For International Development, Bureau For Science And Technology, Washington, D. C., 1983.

78. Schroeder, G. L.,"Agricultural Wastes in Fish Farming," *Water Res*. 11:419-20, 1977.

79. Szendrey, L. M., "The Bacardí Corporation Digestion Process for Stabilizing Rum Distillery Wastes and Producing Methane, IGT Symposium: *Energy From Biomass And Wastes VII*, Orlando, Florida, January, 1983.

80. Truax, R. E., D. D. Culley, Jr., Griffith, M., Johnson, W. A., and Wood, J. P., "Duckweed for Chick Feed", *Louisiana Agric*. 16(1): 8-9, 1972.

81. Tillman, D. A., *Wood As An Energy Resource*, Academic Press, New York, N. Y., 252 pp., 1978.

82. Thompson, W., "U.S. Department of Energy, EIFS Program Official, Idaho Operations Office, Idaho Falls," Personal Communications, August, 1983, Phone: (208) 526-1668.

83. Ubarri-Blanes, A., "Owner and Manager of the Ubarri Dairy Farm, Site of DOE-sponsored EIF Project, Juana Díaz, P.R.", Personal Communications, 1984-85, Phone: (809) 837-2038.

84. Villamil, J., et al., *Water Hyacinths For Clarification Of Wastewaters And The Production Of Energy*, CEER-UPR Publication No. C-36, 30 pp., 1979.

85. Vicente-Chandler, et al., *The Intensive Management Of Tropical Forages In Puerto Rico*. AES-UPR Bulletin No. 187, 1974.

86. Wahlquist, H., "Production of Waterhyacinths and Resulting Water Quality in Earthen Ponds", *Hyacinth Cont. J.* 10:9-11, 1972.

87. Wishart, R. S., "Industrial Energy in Transition: A Petrochemical Perspective", *Science* 199: 614-18, 1978.

88. Wright, R., "Advances in Thermochemical Conversion Of Biomass to Energy" Argonne National Laboratory/DOE Symposium: *Energy From Biomass: Building On A Generic Technology Base*, Proceedings Second Technical Review Meeting, pp. 63-66, April 23-25, 1984.

89. Wadehra, B. L., and Saluja, S. S., "Biogas as an Alternative Energy Source in India", *Fourth Miami Conference On Alternative Energy Sources*, Miami Beach, Florida, p. 326, December 14-16, 1981.

90. Yuan, D. Q., "Utilization of Biogas in the Countryside", *Fourth Miami Conference On Alternative Energy Sources*, Miami Bech, Florida, p. 328, December 14-16, 1981.

FOOTNOTES

[1] Pertinent enacted legislation: Public Law No. 9 (Public Environmental Policy Act), June 18, 1970; PL 94-580 [Federal Resource Conservation and Recovery Act (RCRA)], 1976; and Puerto Rico's PL 70 created the "Solid Waste Management Authority", June 23, 1978.

[2] US-DOE Contract No. DE-FC001-80CS-40376.

[3] "Sordan 70-A", a Sudangrass x Sorghum hybrid developed by the Northrup-King Company.

[4] Section 936 of the U.S. Federal Tax Code has long offered powerful tax incentives for mainland manufacturers to locate their factories in Puerto Rico. Because the current U.S. administration perceives continued 936 activity in terms of lost revenues, Section 936 would be eliminated from the new tax code presently under preparation. In general, any comprehensive, long-term development of insular biomass (Puerto Rico's greatest natural resource), including EIF systems biomass, would benefit from continued existence of Section 936, owing to the need for high-technology industry to participate as biomass processors and consumers.

[5] Implementation of EIF systems with programs competing for limited financial and technical resources can be viewed as a polar counterpart of the "gold rush" agriculture presently under development in Saudi Arabia (54). They are sustained by massive, oil-derived subsidies, and the foreign "agribusiness" interests therein attracted. Such programs, though rare, are not necessarily good.

FIGURE LEGENDS
(Figures not attached.)

Fig. 1. Diagramatic summary of the principal subsystems for collection, bioconversion, and utilization of wastes in a small-farm EIF installation.

Fig. 2-A. Biogas production from a dairy manure/water slurry in an experimental, 10-gallon, transparent-glass fermentor. Photograph by A. G. Alexander, DOE-UPR-EIF project, Juana Díaz, P.R.

Fig. 2-B. Emission of biogas, consisting of approximately 60% methane, as surface bubbles from a fermenting dairy manure/water slurry. Photograph by A. G. Alexander, DOE-UPR-EIF project, Juana Diaz, P.R.

Fig. 3. A fast-growing, tropical fish species (Tilapia nilotica) having potential value in EIF systems as an agent for removing organic materials from wastewater effluents, as a protein food source for human consumption, and as a food supplement in livestock dry-feed rations. Photograph by A. G. Alexander, AES-UPR Lajas Substation.

Fig. 4. Growth trial for the waterhyacinth (Eichornia crassipes), a free-floating, very fast-growing aquatic plant common to tropical and subtropical fresh-water sources. It has potential value (as illustrated) for rapid removal of inorganic substances from EIF wastewater, and as a supplement to farm-waste feedstocks for anaerobic conversion to biogas. Photograph by A. G. Alexander, DOE-UPR-EIF project, Juana Díaz, P.R.

Fig. 5. Aerial view of rum distillery wastes discharged into the Atlantic Ocean near Cataño, P.R., during the early 1970's. In compliance with environment-protection legislation, a large anaerobic waste treatment facility was installed to process such wastes while providing electricity for the distillery. Photograph courtesy of L. Tilly, CEER-UPR staff.

Fig. 6. Milking and feedlot area of the Antonio Ubarri-Blanes dairy farm, site of the DOE-UPR-EIF project in the semi-arid foothills near Juana Díaz, P.R. Photograph by A. G. Alexander.

Fig. 7. Accumulated dairy feedlot manure, stored over long periods for lack of readily-accessible disposal systems. Photograph by A. G. Alexander, DOE-UPR-EIF project, Juana Díaz, P. R.

Fig. 8. Schematic diagram of the energy-integrated, environmental-compliance farm plan for the Ubarri-Blanes dairy farm, DOE-UPR-EIF project, Juana Díaz, P.R.

Fig. 9-A. Application of previously-stored, raw dairy feedlot manure on a seedbed prepared for intensive greenfeed production, DOE-UPR-EIF project, Juana Díaz, P.R. Photograph by A. G. Alexander.

Fig. 9-B. Establishment of a fast-growing tropical forage grass (Northrup King Company variety "Sordan 77"), for use as greenfeed, DOE-UPR-EIF project, Juana Díaz, P.R. Photograph by A. G. Alexander.

Fig. 9-C. Freshy-harvested greenfeed site, remanured and irrigated for rapid regrowth from the stubble, adjoining 5-weeks old napier-grass to be harvested within the next two days, DOE-UPR-EIF project, Juana Díaz, P.R. Photograph by A. G. Alexander.

Fig. 9-D. Feeding of freshly-harvested (field chopped) Sordan 77, to feedlot-confined dairy cattle, DOE-UPR-EIF project, Juana Díaz, P.R. Photograph by A. G. Alexander.

Fig. 10. Napier grass (variety "Common Merker") at 6 months of age, being harvested as a high-lignocellulose, maximum-biomass energy crop, as opposed to the napier grass greenfeed illustrated in Figure 9-C. DOE-UPR-tropical grasses project, AES-UPR Lajas Substation, Lajas, P. R. Photograph by A. G. Alexander.

Fig. 11. High divergence of evaporation potential and moisture received as precipitation, at AES-UPR Fortuna Substation, near the Juana Díaz site of the DOE-UPR-EIF project, in Puerto Rico's semi-arid southern foothills.

Fig. 12-A. Impounded surface runoff, after heavy but brief rainfall, by a permanent earthen dam with overflow, Antonio Ubarri-Blanes dairy farm, Juana Díaz, P.R. Photograph by A. G. Alexander.

Fig. 12-B. Transfer of excess irrigation water to a newly-enlarged storage lagoon, DOE-UPR-EIF project, Juana Díaz, P.R. Photograph by A. G. Alexander.

Fig. 13. Napier grass lignocellulose, harvested and solar-dried at 6 months of age, and ground to pass a 1/2 inch screen with moisture content approximately 15%. Such material when blended with sugarcane molasses can be used as livestock feed, but has vastly greater potential value as a clean, stable feedstock for lignocellulose-based industries. DOE-UPR-tropical grasses project, AES-UPR Lajas Substation, Lajas, P.R. Photograph by A. G. Alexander.

Fig. 14. Schematic diagram of the CBI "Twin Plant" concept, as applicable to dispersed EIF lignocellulose products needed as feedstock at centralized "second plants", in this example for conversion to nitrogenous fertilizers for supply to the original EIF landowners.